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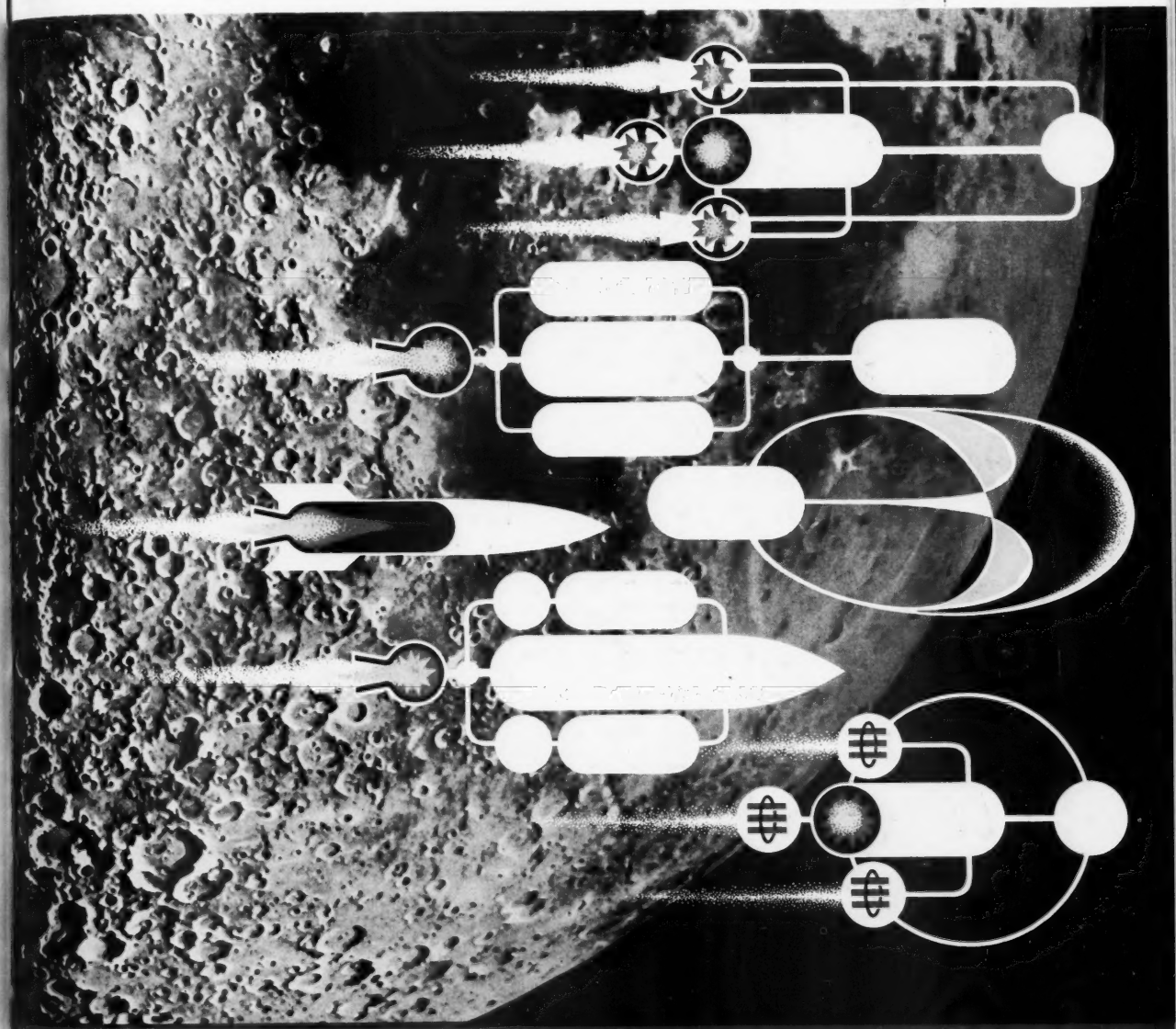
AERO/SPACE ENGINEERING

REVIEW OF CURRENT AND FUTURE TRENDS IN AIRCRAFT • MISSILES • ROCKETS • SATELLITES • SPACECRAFT



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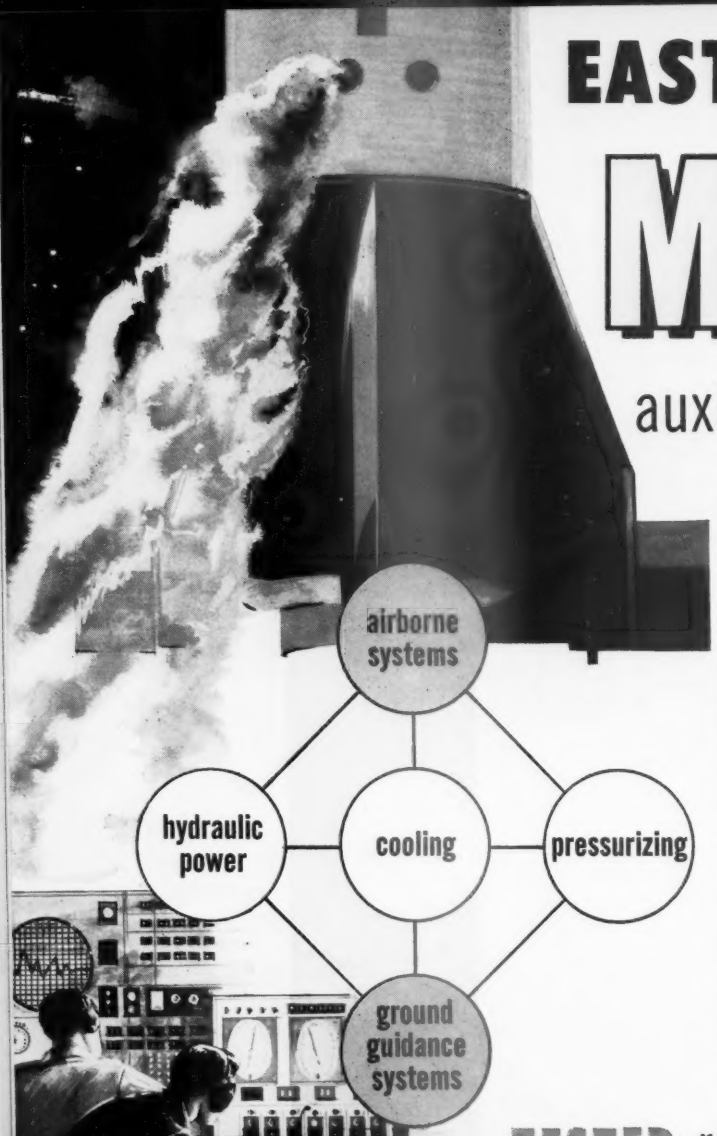
NOVEMBER | 1958

XUM

EASTERN . . . pioneer i

MISSILE

auxiliary power subsystems



Eastern has developed miniature, high-output units that give reliab performance in missile auxiliary power systems. Coordination wi developers at the planning stage permits Eastern continually to enginee lower weight units that allow more fuel load for longer flight duratio Eastern's experience as pioneers of the thermal frontier provides th all-important knowledge to solve temperature problems at each stag of missile development.

HYDRAULIC POWER UNITS

Miniature high-speed gear pumps are powered by aircraft motors u to 24,000 R.P.M., or direct-driven by the turbine with little or n reduction gearing needed. Missile design engineers get maximu flexibility, reliability, and simplicity with separate hydraulic system Eastern has produced power packs with capacity to 1.5 G.P.M. a pressure to 2,500 P.S.I. Units are completely sealed and have pressur ized sumps for operation at any altitude and attitude.

ELECTRONIC TUBE COOLING UNITS

Liquid cooling of heat-producing electronic equipment is an efficient reliable control of temperatures within safe operating limits. B creating designs based on pioneering experience, Eastern provides compact, lightweight equipment for up-to-the-minute missile needs that meet military requirements.

Cooling units have 50 to 50,000 watts dissipation rates, and refrigera tion-type cooling units are furnished from 100 to 6,000 watts. Com to the **leader in the field** for complete and creative engineering help.

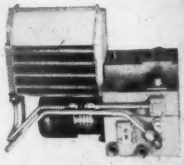
EASTERN PRESSURIZATION UNITS

Vital electronic systems that depend on a supply of precisely controlled dry pressurized air are protected by these units. A continuing program of research and development on compressors, dehydators, and air control systems insures that your Eastern pressurization unit features the very latest advances in this field for compactness, high temperature resistance, and reliability. They are custom-made to your special needs and meet rigid military specifications.

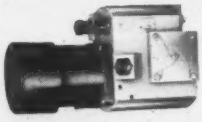
TESTED reliability in auxiliary power

Pressurizing-dehydrating unit used in tracking and guidance system of ground-based missile controls.

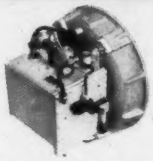
High-speed gear pump provides hydraulic power to missile as integral part of APU system.



Cools high-powered electronic tubes in guidance sections of missiles.



Eastern power-pack gives hydraulic power for missile elevons and wing-folding actuators.



Maintains sensitive reference component within exact temperature limits. Dissipates 350 watts by "boiling off" water in supply tank.

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for 3 of the world's newest airliners

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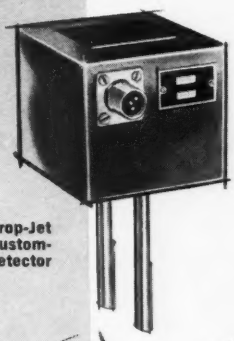
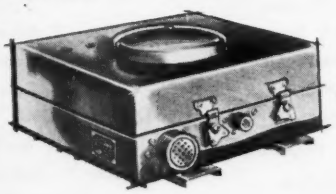
Automatic Ice Detector senses ice build-up precious seconds before pilot can see it. Lightweight sensing "probes" extend into air stream, flash warning to pilot as plane enters icing conditions. Detector has been proved in Arctic Circle operation—is USAF qualified.



New Lockheed Prop-Jet Electra carries custom-engineered Ice Detector system.

New Boeing 707 jetliner has 9 Iceguards on huge empennage.

Automatic System Control. Transistorized "black box" picks up signal from Ice Detector units—automatically actuates deicing equipment. At same instant, flashing light tells pilot he's in icing conditions. It is first fully automatic ice shedding system ever devised.



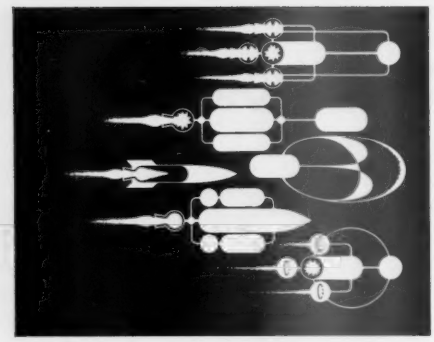
New Convair 880 jetliner will use this fully automatic safeguard — completely automatic Ice Detector and system controller.

Combined Research of Goodyear and National Research Council of Canada produced Iceguard. Automatic Ice Detector system—developed by National Research Council and Canadian Applied Research Limited—is represented solely by Goodyear in the U. S. **For help with your icing problem,** write Goodyear, Aviation Products Division, Akron 16, Ohio, or Los Angeles 54, California.

GOODYEAR

AVIATION PRODUCTS

Iceguard—T.M. The Goodyear Tire & Rubber Company, Akron, Ohio



On our cover

A group of thrust systems for use in various phases of probes into space are etched against an enlarged photo of the moon for a striking introduction to this month's leading technical article (see page 36). Energy sources illustrated are, top to bottom: Arc Jet, Thermonuclear, Solid Propellant (center left), Photon Sail (center right), Liquid or Chemical Propellant, and Plasma Accelerator. The contribution, presented exclusively in Aero/Space Engineering, is "Rocket Propulsion Requirements for Satellites and Moon Missions," by John L. Sloop, Chief, Rocket Engines Branch, Lewis Research Center, NASA.—Cover by DiGeorge

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AERONAUTICAL ENGINEERING REVIEW

AERO/SPACE ENGINEERING

VOLUME 17 / NUMBER 11 November 1958

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A Special Report **27** First International Congress of the Aeronautical Sciences
Six hundred attended from 25 nations. Highlights of the first ICAS meeting in Madrid.

Kenneth S. M. Davidson **35** The Scientific Approach (Editorial)
Timely thoughts from a late Fellow of the Institute, who believed that the rate of scientific discovery cannot be forced.

John L. Sloop **36** Rocket Propulsion Requirements for Satellites and Moon Missions
Lewis Research Center, NASA
There is a big step between tossing a small payload into a satellite orbit and manned space flight.

Abraham Hyatt **45** Some Effects of High-Energy Fuels on Aircraft Performance
Department of the Navy
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S. James Press **51** An Application of Solar Radiation to Space Navigation
Douglas Aircraft Company, Inc.
It appears that a system of space position determination with respect to the sun might be a useful solution to the space navigation problem.

John D. C. Crisp **55** Equivalent Configurations in Flutter Analysis
Massachusetts Institute of Technology
The author finds the equivalence concept has optimum application in two fields—design and remedial studies.

Peter G. Kappus **62** Air-Breathing Power Plants in the Space Era
General Electric Company
"The optimum potential of the air-breathing engine has not yet been realized." Three important jobs are assigned to it.

Leopoldo V. Toralballa **66** Durability Under Varying Stress
New York University
Can it be predicted? Estimates that are trustworthy would be of prime importance; some ideas in this direction are presented.

J. G. McCracken **70** Effects of Gyroscopic Cross Coupling on Missile Automatic Flight Control Systems
Chance Vought Aircraft Company, Inc.
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B. F. Goodrich Pneumatic De-Icers are flush mounted on Grumman Gulfstream

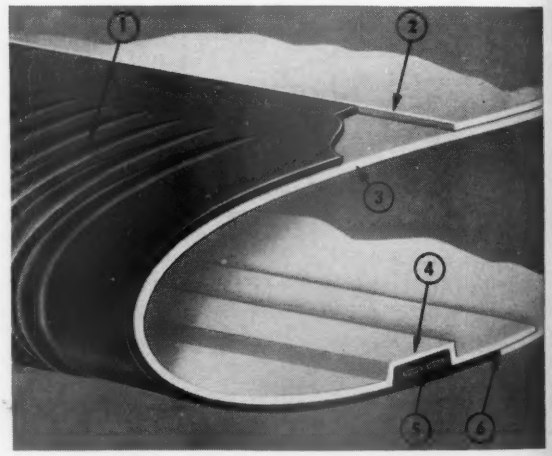
Here are three basic reasons why Grumman engineers selected B. F. Goodrich Pneumatic De-Icers for their new turbo-prop executive transport — the Gulfstream.

First—B.F.Goodrich Pneumatic De-Icers are the most dependable and effective method of ice removal. Their positive action cracks off ice regardless of accretion rate. And with this pneumatic de-icing system there is no problem of "refreezing run back".

Second—B. F. Goodrich Pneumatic De-Icers impose no heavy drain on engine power or fuel consumption. Power requirements are negligible. Furthermore, the complete system is far lighter in weight than any other.

Third—B.F.Goodrich Pneumatic De-Icers are aerodynamically efficient. Advanced Gulfstream design provides for recessed leading edges (right), permitting flush fit of De-Icers with no change in airfoil contour.

There are many other reasons why you will want to specify B. F. Goodrich Pneumatic De-Icers for your own planes. They are all discussed in "The B.F.Goodrich Pneumatic De-Icer Story". For your free copy, write: *B. F. Goodrich Aviation Products, a division of The B. F. Goodrich Company, Akron, Ohio.*



① De-Icer, inflated ② Wing recess at trailing edge of De-Icer ③ Wing skin ④ Wing recess for De-Icer manifold ⑤ Flush-type tube manifold ⑥ Wing recess at lower trailing edge

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IAS News Notes

November 1958

NASA ADMINISTRATOR T. KEITH GLENNAN will be the principal speaker at the Institute's 27th Annual Meeting Honors Night Dinner - at the Astor Hotel, Tuesday, January 27. The meeting will be highlighted by such sessions as those on Space Exploration, Propulsion, Management, and Supersonic Jet Transports.

WHAT ARE THE RESPONSIBILITIES OF IAS MEMBERSHIP? This question is taken up in next month's issue by IAS President Edward C. Wells in a guest editorial of interest to all members.

LT. GEN. DONALD L. PUTT, USAF (Ret.), an IAS Fellow, has been elected President of a new firm - United Research Corporation - formed by United Aircraft Corporation "to sponsor and support basic research in fields pertinent to its interests." Scientific Directors under General Putt include two other IAS members, C. Richard Soderberg (F) and H. Guyford Stever (F), Dean and Assistant Dean, respectively, M.I.T.

NEW CORPORATE MEMBER: AC Space Plug Division, General Motors Corporation, has joined the growing list of IAS Corporate Members. The company is located at Flint, Michigan.

A/SE FOR DECEMBER will carry an Index to Volume 17, covering issues from January to December 1958. All technical articles, Institute news, editorials, and necrology for the year will be listed. Articles will be indexed by subject and author.

THE IAS MOURNS the loss of the following members: B. W. Ainsworth, Harold P. "Hal" Henning, John J. Herfurth, John L. Genta, and John C. Fowler. Their necrologies will appear next month.

* * * * * *

NATIONAL MEETINGS CALENDAR

Nov. 6-7	National Specialists Meeting on Dynamics and Aeroelasticity, Texas Hotel, Fort Worth. Sponsored by Texas Section.
Dec. 17	Wright Brothers Lecture, Natural History Building Auditorium, Smithsonian Institution, Washington, D. C. French aeronautical research will be discussed by Maurice Roy.
1959	
Jan. 26-29	Twenty-Seventh Annual Meeting, Astor Hotel, New York. Honors Night Dinner, Tuesday, January 27.
Mar. 5-6	Flight Propulsion Meeting (Classified), Hotel Carter, Cleveland.
June 15-18	National Summer Meeting, Los Angeles, California
Oct. 5-16	Seventh Anglo-American Aeronautical Conference, New York, N. Y.
Oct. 29-31	National Midwestern Meeting, Wichita, Kansas.

* * * * * *

FLIGHT TEST FELLOWSHIP WINNERS - where are they now? Read the answer to this question, and interesting sidelights, in Aero/Space Engineering for December. (Fellowship application data are carried on page 25 in this issue.)

SECTION MEETINGS CALENDAR

Nov. 5 Baltimore: Classified Dinner Meeting, Aircraft Armaments, Cockeysville. (Dinner at 6:30, lecture at 8.) "The Guided Missile Program" by Brig. Gen. A. W. Betts.

Nov. 11 Los Angeles: Specialist Meeting, IAS Building, 8 p.m. "Supersonic Transports" panel discussion by T. F. Cartaino, R. B. Johnston, and T. F. Kirkwood.

Nov. 11 Detroit: Plant tour, Continental Aviation and Engineering Corporation, gas turbine production facilities, Toledo, Ohio.

Nov. 11 Wichita: Dinner Meeting, Innes Tea Room, 6:30 p.m. "Aeronautical Research and Development in the U. S. Army" by Col. G. P. Seness, Jr.

Nov. 11 Tulsa: Dinner Meeting, Alvan Plaza Hotel. (Social at 6:30, dinner at 7.) "A Simple Means for Solving Difficult Viscous Flow Problems" by August Raspet.

Nov. 12 Chicago: Joint Meeting with ARS on "Man in Outer Space (Human Factors in Space Flight)." Time and place to be announced.

Nov. 18 Washington: Dinner Meeting, Occidental Restaurant. (Social at 6:45, dinner at 8.) "Assessment and Measurement of Human Responses and Performance in Space" by A. W. Hetherington, Jr., and Capt. N. L. Barr, USN, (MC).

Nov. 19 Atlanta: Dinner Meeting, Chamblee NAS Officers Club, 7 p.m. "The Air Traffic Control System - Problems and Proposed Solutions" by C. P. Rosacrans.

Nov. 19 Niagara Frontier: Technical Meeting, Cornell Aeronautical Laboratory Auditorium, 8:30 p.m. "High Energy Fuels" by P. A. Stranges.

Nov. 20 Los Angeles: Dinner Meeting, IAS Building. (Social at 6, dinner at 7.) "Needed for a Successful Space Program - A Fresh Approach to R&D" by Commander George Hoover, USN.

Nov. 25 Los Angeles: Specialist Meeting, IAS Building, 8 p.m. "A Physical Evaluation of Mass Transfer Cooling" by J. P. Hartnett.

Dec. 19 Texas: Dinner Meeting, Western Hills Inn, Wright Brothers Lecture on French aeronautical research by Maurice Roy.

JOINT MEETINGS CALENDAR

Apr. 5-10 1959 Nuclear Congress, Municipal Auditorium, Cleveland.

May 25-27 National Telemetering Conference, Cosmopolitan Hotel, Denver. Sponsored by IAS, ARS, ISA, and AIEE.

June 11-13 1959 Heat Transfer and Fluid Mechanics Institute, University of California, Los Angeles. Cosponsored by IAS.

* * * * * *

XUM

IAS News

. . . a record of people and events of interest to Institute Members

French Scientist to Deliver 22nd Wright Brothers Lecture

Maurice Roy to Report on French Aero Research in Washington, December 17

MAURICE ROY, a leading contributor to French aero/space science, will deliver the IAS Wright Brothers Lecture, December 17, in the Natural History Building Auditorium, Smithsonian Institution, Washington, D.C.

Mr. Roy will discuss "Means and Examples of Aeronautical Research in France." He has been Director General, Office National d'Etudes et de Recherches Aéronautiques (ONERA), since 1949.

The lecture will be repeated in Cleveland on December 18, in Dallas on December 19, and in Los Angeles on December 22.

This lecture, twenty-second in a series endowed by the Vernon Lynch Fund, will begin with a survey of the main branches of aeronautical research performed in France, particularly by ONERA, and will be followed by analyzed illustrations. These will cover research in studies of structural flutter and aerothermoelasticity, combustion, materials, high-lift devices, air intake at supersonic speeds, experiments with ram-jets at high altitude, the form and visualization of certain types of flow, and the dynamic stability of aircraft and missiles. Mr. Roy also will present several examples that cover the development of instruments for measurements and will describe research equipment and STOL and VTOL work.

Mr. Roy will not discuss problems of space flight, although he has said it has created a demand for research comparable to that which arose at the time of the Wright brothers' Kitty Hawk flight.

Prolific Writer

Mr. Roy is well qualified to join the select list of Wright Brothers lecturers. He has published some 150 articles on thermodynamics, mechanics, dynamics of fluids, thermal engines, aeronautical propulsion, and jets and rockets.

He was first in his graduating class at the Ecole Polytechnique in 1919. He also was graduated from the National School of Mines in 1922 and in 1923 earned a Doctor of Science degree from the University of Strasbourg.

Mr. Roy has taught at several institutions of higher education in France, many of them during the same span of years. He taught Thermodynamics and Machines at the Ecole Supérieure du Génie Rural (School of Rural Engineering) from 1927 to 1935; Aviation Mechanics at the Ecole Nationale Supérieure de l'Aéronautique (National School of Aeronautics) from 1930 to 1940; Thermal Engines at the Ecole Nationale des Ponts et Chaussées (National School of Civil Engineering) from 1925 to 1949; has been Professor of Mechanics at the Ecole Polytechnique since 1947; and Professor at the Centre d'Etudes Supérieures de Mécanique (Center for Mechanical Studies) since 1946.

Held Important Posts

In addition to being ONERA Director, Mr. Roy has held or still holds the following positions:

Administrator, Société Nationale d'Etude et de Construction de Moteurs d'Aviation (National Society for the Study and Construction of Aircraft Motors) SNECMA.

Member, Conseil Scientifique du Commissariat à l'Energie Atomique (Scientific Council of the Atomic Energy Commission).

President, Association Technique pour la Turbine à Gaz (Technical Association for Gas Turbines).

Vice-President, Association Technique Maritime et Aéronautique (Technical Maritime and Aeronautical Assocation) ATMA.

Maurice Roy

Secretary General, Union Internationale de Mécanique Théorique et Appliquée (International Union of Theoretical and Applied Mechanics) IUTAM, 1956.

Past President, Société Mathématique de France (Mathematical Society of France) 1956.

President, Société Française des Mécaniciens (French Mechanics Society).

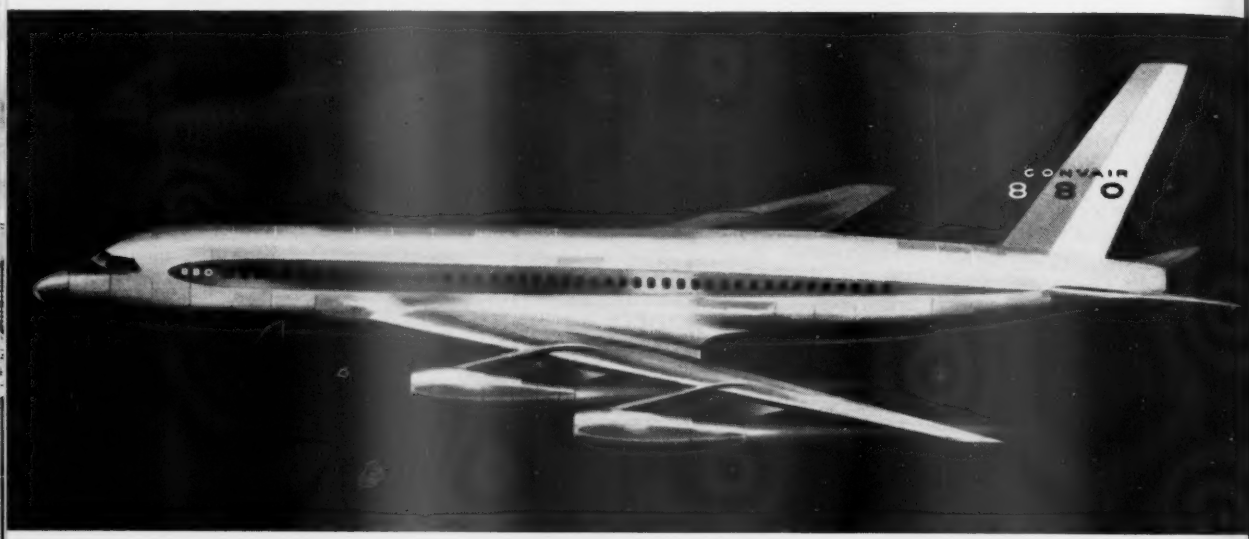
President, Executive Committee, International Council of the Aeronautical Sciences.

Energetic Conferee

His leadership of the ICAS Executive Committee won much respect from the delegates at the organization's first International Congress in Madrid, September 8–13. Mr. Roy was given the authority and responsibility for developing the program. In addition to this complex task, he presented a paper, "Supersonic Propulsion by Turbojets and Ram-jets," at the first session, and he opened and closed the Congress.

Mr. Roy is an IAS Fellow and a Fellow of the Royal Aeronautical Society. He was elected a Correspondent, Academy of Sciences for the Section on Mechanics in 1937 and a Member of the Academy in 1949. He was named a Commander of the Legion of Honor in 1954 and received an Honorary Doctorate degree from the University of Brussels in 1956.

Boeing 707 and Convair 880 rely on Chatham power conversion units

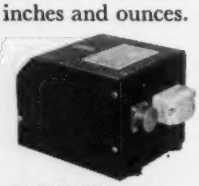


THE Boeing 707 and Convair 880 represent the very latest developments in luxurious air travel. Standard equipment on both includes power conversion units made by Chatham—world's number one maker of power supplies for missiles and military and commercial aircraft.

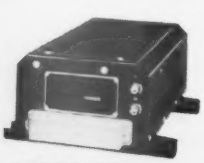
Chatham airborne conversion equipment features minimum size and weight. Because Chatham makes its own solid-state components—silicon, germanium, selenium—our designers are not limited by available stock and can tailor components to fit power supply design, shaving excess inches and ounces.

Reliability is unsurpassed. Chatham power supplies show a uniformly high performance record in aircraft of all types and each unit reflects a long-standing reputation for trustworthy electronic equipment.

Chatham has many power supplies in stock, ready to go . . . or will design and produce a unit to your specifications. Either way, you can fill any power conversion need—AC to DC, DC to DC, DC to AC—with an efficient, high reliability unit made by Chatham. Contact: Chatham Electronics, Division of Tung-Sol Electric Inc., Livingston, New Jersey.



SILICON UNIT
Model 28VS50



SELENIUM UNIT
Model 28V50C

CHATHAM ELECTRONICS
division of
TUNG-SOL ELECTRIC INC.

CHATHAM ... *world's leading supplier of airborne conversion equipment.*

IAS Members Advised They Must Initiate Regrading Machinery

Is your IAS membership grade a true reflection of your professional standing?

If you are graded Associate (A) or Member (M), you may be eligible for advancement. But *you* must take the first step: Obtain an "Application for Advancement in Grade" from your Section Membership Committee or Secretary, or from Membership Department, IAS National Headquarters, 2 E. 64th St., New York 21, N.Y. When properly completed, the application will give the National Membership Committee an up-to-date record of your experience to help determine your new grade.

General qualification for Member grade is 8 years' professional work and recognized standing in the field. Four references are required, two of whom should be IAS members.

Advancement from Member to Associate Fellow (AF) calls for 12 years' professional practice with responsibility for important work in the field or outstanding original contributions. References required: four IAS members, two must be Fellows or Associate Fellows. (Fellows are elected by ballot of existing Fellows and Honorary Fellows.)

Some 225 members advanced in grade during the first 7 months of 1958. Last year's total was 311.

Douglas Promotes Five IAS Members

Five IAS members received new assignments in Douglas Aircraft's recent realignment of Engineering Division functions.

Edward F. Burton (F), former Chief Engineer, Santa Monica Division, was named Director, Transport Aircraft Systems Engineering.

Edward H. Heinemann (F), former Chief Engineer, El Segundo Division, is now Director, Combat Aircraft Systems Engineering. (Mr. Heineman is a member of this magazine's Design, Structures, & Materials Editorial Advisory Committee.)

Elmer P. Wheaton (AF), formerly Chief Missiles Engineer, was appointed Director, Missiles and Space Systems Engineering.

All three directors will report to Arthur E. Raymond (HF), Vice-President, Engineering.

Former assistants to the new directors, who were moved up to Chief Engineer positions in their divisions, include Leo J. Devlin, Jr. (F), El Segundo; and R. L. Johnson (M), Missiles and Space Systems.

San Diego Section Dedicates Library

A new library of aero/space science and engineering literature was dedicated at the IAS San Diego Building on August 29. The Major Reuben H. Fleet Aeronautical Library was a gift from the man whose name it bears.

The dedication, marked by a dinner in honor of Major Fleet, was attended by many of his personal friends. He was cofounder of Consolidated Aircraft, now Convair, a Division of General Dynamics Corp.

Artist Justin C. Gruelle painted a biographical portrait of Major Fleet which was unveiled at the dedication. Guests included C. T. Leigh, former Vice-President, Consolidated; Tom Bomar, former head, Aviation Department, San Diego Chamber of Commerce; I. M. Laddon, former Executive Vice-President, Consolidated, and now a director, General Dynamics Adm. Leslie Gehres (master of ceremonies); and members of the Section.

Giannini Plasmadyne Is New Corporate Member

Giannini Plasmadyne Corp., a firm that applies plasma technology to aero/space research and development, has become a Corporate Member of the Institute of the Aeronautical Sciences.

The company has active R&D projects in areas of electric propulsion systems, hyperthermal wind tunnels, hypersonic aerodynamic phenomena, nose cone and leading-edge testing and materials, and materials for aircraft nuclear power plants. Research in long-range detection of hypersonic vehicles also is in progress.

The firm sells commercially complete plasma-generating systems which it calls Plasmatrons. They make available a continuous, controlled source of plasmas at temperatures up to 25,000°F. Air, nitrogen, and argon are some of the working fluids used. Contamination is said to be less than 100 parts per million.

Plasmatrons are also used as propulsion units, with helium as the working fluid and no expanding nozzle. The units are said to yield specific impulses up to 600 sec.

High melting-point spray materials can be introduced in powdered form into the Plasmatron working fluid where they are vaporized. The jet of plasma carries the vapor to the object to be sprayed where it condenses, firmly bonded to the substrate. The company says this process has been used to spray such substances as tungsten (melting point, 6,092°F.) and titanium carbide (5,660°F.) on metal and nonmetal substrates.

Company headquarters are at 3839 S. Main St., Santa Ana, Calif.

At the dedication of the Major Reuben H. Fleet Aeronautical Library are *(left to right)* Nash Williams, Library Committee Chairman; Major Fleet, who presented the library to the IAS San Diego Section; and Peter Beck, Historical Committee Chairman.

Necrology

George B. Pegram

George B. Pegram (AF), President Emeritus, Columbia University, and an important figure in the development of the atom bomb, died on August 12. He was 81 years old.

Dr. Pegram, a Founder of the IAS, began to assemble at Columbia in 1939 the scientists who made possible the atom bomb. He brought his fellow nuclear physicists Enrico Fermi and John R. Dunning to the United States, and to Columbia, to help carry out on January 25, 1939, the first successful demonstration in America of uranium fission.

After Pearl Harbor this program was moved to the University of Chicago by the Government. The other scientists went with it, but Dr. Pegram became Vice-Chairman, Central Advisory Committee, Manhattan Engineering District. He was named to the first Board of Directors of the Oak Ridge Institute of Nuclear Studies and helped to found the Brookhaven National Laboratory.

Dr. Pegram was born in Trinity, N.C. He graduated from Trinity College, now Duke, in 1895, and joined Columbia's faculty as an assistant in physics in 1900. His Ph.D. thesis, written at Columbia in 1903, was one of the first American studies in radioactivity.

In 1907 and 1908, he studied at Cambridge University, England, and at the University of Berlin, under Max Planck, whom he persuaded to visit the United States and lecture at Columbia.

Among Dr. Pegram's scientific contributions were measurements of the size of the neutron and, with Dr. Dunning, the development of a device for measuring component parts of the atom and demonstrating the possibility of transmuting one element into another.

Seven universities awarded him honorary doctorates, and he was past president of the New York Academy of Sciences and the American Physical Society, past chairman of the Anglo-American-Hellenic Bureau of Education, and former treasurer of the American Physical Society.

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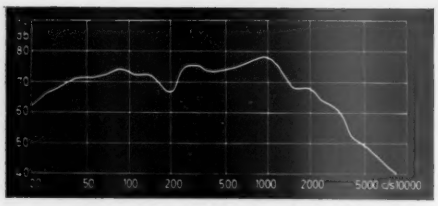
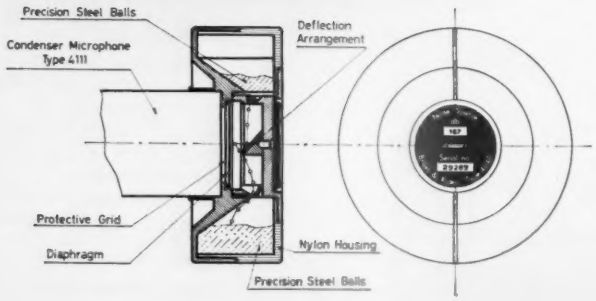
Especially designed to be used with standard measurement microphones.



Typical frequency spectrum of the sound radiated from Model 4240 (plotted on spectrum level basis).



Drawing showing the principle of operation of Model 4240.

The Noise Source Model 4240 is a small, self-contained acoustic calibrator for quick and reliable calibration of sound measurement systems. It mechanically generates a wide band sound at an SPL of approximately 108 db for about 14 seconds by means of 14,000 1 mm precision steel balls striking a metal diaphragm. Such a high SPL makes the effect of average background noise on calibration negligible.

The wide band spectrum of the noise source enables a rapid check of the calibration and indicates any significant shift in the frequency response of a sound measurement system. It may also be used to establish a permanent reference SPL when sound measurements are taken and recorded on magnetic tape or graphic level recorder in the field or laboratory.

The SPL of each Model 4240 is individually calibrated in terms of its RMS value and is accurate to ±1 db. The calibration of the unit varies less than 0.5 db over the temperature range of 32 to 160° F.

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Forms Available, Competition Open Now for Flight-Test Engineering Fellowship

Interested in receiving an IAS Flight-Test Engineering Fellowship?

A Bachelor's degree in engineering and United States citizenship are the main qualifications for the 1959 competition—worth $7,300 over a 2-year period.

Write for applications now—closing date is March 1, 1959—to Flight Test, Institute of the Aeronautical Sciences, 2 E. 64th St., New York 21, N.Y. (This initial request should be endorsed by a sponsor.) Candidates may be enrolled in an educational institution or employed in industry when making application.

A First-Year Fellow receives a stipend of $1,500, $750 for tuition, and $850 for university departmental expenses. A Second-Year Fellow receives $2,000 stipend, $750 tuition, and $1,450 for departmental expenses. Second-Year renewal depends upon satisfactory performance during the first year.

Frank Mansur (M), a member of this magazine's Electronics Editorial Advisory Committee, has joined Lockheed Aircraft Corp. as Military Sales Representative for Electronics. He formerly was Manager, Marketing, Eitel-McCullough, Inc.

IAS News

News of Members

Sam Emer (A) has been promoted to Design Engineer "A" and transferred from Lockheed Aircraft's Georgia Division to the Missile Systems Division.

Frank H. Erdman (A), formerly Assistant Manager, Washington Office, The Ralph M. Parsons Co., has been named President, Kett Technical Center, Inc., Research and Development center of U.S. Industries, Inc.

Fredric Flader (F), a Founder of the IAS, has joined the University of Miami faculty as Associate Professor, Industrial Engineering. He formerly was General Manager, Fredric Flader Division, Eaton Manufacturing Co.

James C. Floyd (M) has been invited by The Royal Aeronautical Society to give its 1958 British Commonwealth Lecture. Mr. Floyd, an RAeS Fellow, is Vice-President—Engineering, Avro Aircraft Limited, Malton, Ontario, Canada.

Theodore A. Fore (A) has been promoted to the post of Manager, Requirements and Specifications Department, Lockhead Missile Systems Division, Van Nuys, Calif. He formerly was Manufacturing Engineer in the department.

Harold E. Francis (M) has been named Chief Project Engineer, Chandler-Evans Co. Mr. Francis had been Assistant Chief Engineer, Wright Aeronautical Division, Curtiss-Wright Corp.

Comdr. W. H. Livingston, USN, (M), formerly a student at the U.S. Naval War College, Newport, R.I., has been appointed Director, U.S. Naval Test Pilot School, NATC, Patuxent River, Md.

Lt. Col. Ralph D. McKee USAF, (M), has been appointed Chief, SM-62 Division, Directorate of Cruise Missile Test, AFMTC, Patrick AFB, Fla. He had been a student at the Air Command and Staff College, Maxwell AFB, Ala.

F. E. Newbold, Jr. (M), Vice-President and General Manager, Fairchild Stratos Division, has taken over responsibility for Corporate Planning and the firm's Engine and Guided Missiles Division's operations.

William J. Pattison (M), formerly Director of Military Relations, The Garrett Corp., has been elected Vice-President in charge of sales for the firm's AiResearch Manufacturing Division, Los Angeles, Calif.

R. James Pfeiffer (A), formerly Executive Director, Corporate Customer Relations, has been promoted to Vice-President—Marketing, Commercial Transport Division, Fairchild Engine and Airplane Corp.

Abner Rasumoff (M), formerly Head, Loads Section, Hughes Tool Co., Aircraft Division, has joined The Ramo-Wooldridge Corp., Space Technology Laboratories.

Henry Rempt (M), Lockheed Electronics & Armament System Division Engineer, has been elected President, Institute of Navigation at the University of California, Berkeley, Calif.

Walter F. Ring (A), formerly Project Engineer, Industrial Acoustics Co., Inc., is now President of a new firm, Silence Inc., specializing in aircraft, industrial, and medical noise control.

Col. Harry G. Spillinger (AF), who retired from the Air Force on July 31, has been named Manager of the newly created Systems Reliability and Safety Control group in the Boeing Airplane Co. Systems Management Office. Colonel Spillinger, an IAS Founder, was in the Air Materiel Command at Wright-Patterson AFB.

William W. Thomas (A) has joined Lockheed Aircraft Corporation's Georgia Division as Chief Draftsman. He held the same title with Vertol Aircraft before joining Lockheed.

Stephen P. Timoshenko (F), Professor Emeritus, Stanford University, Stanford, Calif., has been awarded the Elliott Cresson Medal at the Franklin Institute's Medal Day ceremonies. The medal is given for discovery or original research.

John F. Victory (M), NACA Executive Secretary and its first employee, has been awarded the NACA Distinguished Service Medal by Chairman James H. Doolittle.

(*Continued on page 74*)

Major Gen. Harry G. Armstrong, USAF (MC), an IAS Fellow and 1941 John Jeffries Award winner, retired from the Air Force in September after nearly 30 years of service. A pioneer in aviation and space medicine and former Surgeon General, he was stationed at USAFE Headquarters in Wiesbaden, Germany, before he retired.

DATELINE World

PROFESSIONAL NOTES AND REPORTS

Engineering and Scientific Briefs from Correspondents Around the Globe

Test Pilot Discusses Soviet Mi-1 Helicopter

◆ In the Soviet magazine *Wings of the Nation*, R. Kaprelyan, Test Pilot, First Class, gives some interesting pointers on how to handle the general-purpose Mi-1 helicopter. Kaprelyan piloted both the Mi-4 and the big Mi-6 helicopters to world lift records, hence can be considered an authority on his subject.

Kaprelyan says that the rotor blades of the Mi-1 have an even degree of twist which attains a maximum of 4 deg. at the tips. "Burble" (retreating-blade stall) at high speeds causes strong vibration and deteriorates controllability to the danger point. In order to avoid the burble, Kaprelyan advises, the pilot should keep the engine speed above 1,700 r.p.m. and limit the forward flight speed as shown in Table 1.

The best altitude for a lengthy "itinerary" flight (cruising-speed trip), the article states, is from 800 to 1,000 meters (approximately 3,000 ft.), and the most convenient speed is 135 to 140 kmh (approximately 75 knots). With these conditions, the "throttle corrector" should be completely shut off, the main rotor pitch will be about 10.5 deg., and the engine speed will be about 1,800 to 1,850 r.p.m. A range of flight of 385 km. (210 nautical miles) and a flight duration of 2.75 hours will thus be obtained. By reducing the forward flight speed to 90 kmh (50 knots), the duration can be increased to 3.4 hours (the range will decrease to about 170 nautical miles).

Air navigation safety, Kaprelyan comments, is realized in a helicopter, as in other aircraft, by means of conventional compasses, gyro horizon, RPK-10 radio compass, and command radio sets. He states that the scope of normal centering (center of gravity travel) for the Mi-1 helicopter is from 52 mm. (2.05 in.) aft of the main rotor shaft to 160 mm. (6.30 in.) forward.

Minimum permissible gliding speeds (under power) are given in Table 2.

The Soviets have produced several versions of the Mi-1 for such varied uses as crop-dusting; mail, freight, and passenger transport; and for casualty evacuation, when a removable pannier for a stretcher is mounted on each side of the cabin.

TABLE 1

Altitude	Speed
Ground level	170 kmh (93 knots)
1,000 m. (3,280 ft.)	165 kmh (90 knots)
2,000 m. (6,560 ft.)	160 kmh (87 knots)
3,000 m. (9,840 ft.)	150 kmh (82 knots)

TABLE 2

Altitude	Speed
Up to 1,000 m. (3,280 ft.)	40 kmh (22 knots)
2,000 m. (6,560 ft.)	70 kmh (38 knots)
3,000 m. (9,840 ft.)	80 kmh (44 knots)

Soviet Article Describes Helicopter Weighing 28½ lbs.

◆ The magazine *Soviet Aviation* has described and illustrated a helicopter, which is said to weigh only 28½ lbs. According to the article, the unique aircraft is currently under test.

A simple fixed-pitch, rigid rotor of the contrarotating coaxial type and of extremely small diameter is rotated by jets at the blade tips. The hub structure between the rotors encloses a turbine and a combustion chamber in which a kerosene-air mixture is burned. The turbine has no fixed blades, alternate rows of blades being attached to the upper rotor and the lower rotor, respectively. The products of combustion are mixed with the excess cool air from the turbine and piped through the rotor blades to tip jets. The power plant is rated at 5 hp. Fuel is injected into the combustion chamber by a rotor-driven pump. Directional control appears to consist only of fore-aft tilt of the entire rotor, with height control accomplished through rotor r.p.m. change.

Operation of the machine consists of "walking" it until an obstacle is reached, whereupon the operator switches on full engine power, steps on the footboard, pushes away from the ground, and flies over the obstacle. The pilot is held to the machine by a waist belt and is provided with a small seat.

Stability of the machine is very good, it is said, and is supplemented by a device between the rotors, which is not described.

Japanese Improve Ceramics by Adding Beryllium Oxide

◆ In Japan, the Ceramics Branch of the Electro Material Laboratory, Government Industrial Research Institute (Nagoya, Japan) under the agency of Industrial Science and Technology, has succeeded in making high-thermo-shock resistant ceramics by the addition of beryllium oxide. The application of this material would be in microwave electron tubes.

This process resulted from a study intended to improve the thermal shock resistance of insulators of the diopside ($CaMgSi_2O_6$) type which are made by using magnesium oxide from sea water. The addition of 5 to 15 per cent beryllium not only improved resistance to thermal shock but also improved the dielectric properties.

While this improvement is not of sufficient individual significance to rank as a major accomplishment, it is a definite and promising step in the course of making electronic components operational under increasingly severe operating environments.

Special Clothing Developed for Use in Atomic Laboratories

◆ An item noted in a Polish publication announces that, after several years of research, Soviet scientists have developed special clothing which provides complete protection for workers in atomic laboratories against radioactive wastes and radiation. Made from seamless plastic and airtight, the new clothing has been given general recognition by experts from many countries, the item states.

A transparent plastic helmet is part of the outfit. Air is pumped to the wearer by special equipment in much the same manner as it is supplied in diving suits.

ICAS

1ST INTERNATIONAL CONGRESS OF THE AERONAUTICAL SCIENCES

On the streets outside Madrid's Instituto Nacional de Previsión and Palacio de Comunicaciones, flags and signs indicated location of ICAS meetings.... The First Congress symbol (right), showing Don Quixote on his horse flying over the ancient Spanish castle Peñafiel, was designed for the occasion by the local Arrangements Committee under the Chairmanship of Col. Antonio Pérez-Marín.

Madrid, Spain September 8–13, 1958

SOME 600 DELEGATES from 25 countries of the world assembled in Madrid to inaugurate a series of international conferences in the aeronautical and space sciences. Organized under the aegis of the International Council of the Aeronautical Sciences (ICAS) under the leadership of Honorary President Dr. Theodore von Kármán, the successful First Congress has laid the groundwork for similar meetings at 2-year intervals in the future. The full record of the papers presented and of the subsequent discussions will be made available in a two-volume edition of the Congress *Proceedings* to be published early in 1959 by Pergamon Press, Ltd., of London. All enquiries concerning the *Proceedings* should be addressed to the Publisher at Pergamon House, 4 Fitzroy Square, London, W.1, England. Some Congress highlights appear in the pages that follow.

THE GENERAL ASSEMBLIES

The Congress opened (September 8) and closed (September 13) with General Assemblies at the Instituto, with Maurice Roy, Chairman, ICAS Executive Committee, in the chair. Official addresses of welcome were made by The Honorary President and Col. Luis de Azcárraga, President of the Asociación Española de Ingenieros Aeronáuticos. Spain's Minister of Air and the Lord Mayor of Madrid also participated in the opening session. Announcement of plans for the future and resolutions of thanks and appreciation to the hosts were included in the closing session. Two lectures—The Daniel and Florence Guggenheim Memorial Lecture and The Juan de la Cierva Memorial Lecture—followed the General Assembly on the first day.

A part of the audience in the beautiful Instituto Auditorium at the Opening Session.

THE FIRST Guggenheim Memorial Lecture was presented by Dr. von Kármán. His subject was "Some Significant Developments in Aerodynamics Since 1946." This scholarly presentation by the dean of world aerodynamicists set the tone of the entire Congress at the highest scientific level. His paper will appear in full in the Conference *Proceedings*.

The first Juan de la Cierva Lecture, presented by Pedro Blanco, was titled "Juan de la Cierva and His Contribution to the Development of Rotary Wing Aircraft." This lecture, to which delegates of the Congress were especially invited, was sponsored by the Asociación Española de Ingenieros Aeronáuticos.

The Congress was honored by the presence of The Honorable Harry F. Guggenheim whose foresight and support made possible the ICAS organization. Before introducing Dr. von Kármán he said:

"When man's early longing for flight was achieved in our generation, we hoped that breaking down the barriers of sea and mountain, and the concomitant close contact of people throughout the earth, would also break down the agelong taboos of tribe, race, and religion and lead to another more recent dream of the brotherhood of man.

"We must not be discouraged because we have not yet reached our goal. After all, flight has only been mastered in recent years. But we must make renewed efforts and greater

The Honorary President, Dr. Theodore von Kármán, during the reading of the first Daniel and Florence Guggenheim Memorial Lecture.

The Honorable Harry F. Guggenheim introduces Dr. von Kármán at the Opening Session of the First International Congress.

ICAS

speed toward our goal, because the flight sciences have opened up to man new and overawing powers of human destruction.... Today man is for the first time faced with the stark realization that if he lets loose the new forces of destruction he destroys himself.

"Let us do everything in our power to stimulate this awareness. This Conference is one excellent means of accomplishing this purpose. The flight and allied sciences must move ahead still farther into the mysteries of life and the universe, even if their solutions increase man's power of destruction. Man's desire to use this power will decrease in inverse ratio to man's awareness of his danger of self destruction."

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A tête-à-tête conference with ICAS Honorary President and Maurice Roy, Chairman of ICAS Executive Committee. Col. Luis de Azcárraga, President of Asociación Española de Ingenieros Aeronáuticos, in the background (left).

...AMONG THOSE PRESENT

Many high-ranking officers and distinguished civilians attended the First Congress. It is impossible to list them all in these pages. The sampling herein presented is, however, an indication of the caliber of those who attended. A breakdown of the attendees by country shows: Argentina, 1; Australia, 2; Belgium, 9; Brazil, 1; Canada, 11; China, 3; France, 29; Germany, 34; Hungary, 2; Israel, 3; Italy, 28; Japan, 5; The Netherlands, 9; Poland, 7; Portugal, 1; Rumania, 2; South Africa, 1; Spain, 178; Sweden, 16; Switzerland, 4; Turkey, 1; United Kingdom, 73; United States, 157; U.S.S.R., 9; and Yugoslavia, 3.

At the Opening Session— The Honorable Harry F. Guggenheim; The Honorable Garrison Norton, U.S. Assistant Secretary of the Navy for Air; and RADM Luis de Florez, USNR. In the next row, Brig. Gen. R. L. Wassell, USAF, and Brig. Gen. H. F. Gregory, USAF.

In informal discussion, Dr. Nicholas J. Hoff of Stanford; Lt. Gen. L. C. Craigie, USAF (Ret.), of American Machine and Foundry; and Elmer A. Sperry, Jr., of Sperry Products.

Dr. Hugh L. Dryden, NASA; E. T. Jones, Ministry of Supply, U.K.; and Richard Greinacher, Service Technique Militaire; at the von Kármán lecture.

Left to right, Sir Arnold Hall, President, Royal Aeronautical Society, and Edward C. Wells, President, IAS, listen attentively while IAS Director and Major Gen. John Sessums, USAF, test directional effects of radio receiver antennas. Major Gen. Marvin Demler, USAF, on right.

TECHNICAL SESSIONS

BETWEEN Tuesday morning (September 9) and Saturday morning (September 13), 45 papers were presented in 14 technical sessions. Printed programs included abstracts of the papers in four languages—English, French, German, and Spanish. Papers were generally presented in the language of the author and were simultaneously made available in the other languages by a battery of translators using the IBM multilingual sound system (the photograph below shows the delegates picking up the multichannel transistorized receivers and headsets outside the Conference halls). Discussions were permitted from the floor in any of the four Congress languages, but discussers were requested to submit their remarks in writing at the conclusion of the Congress so that they can be included in the *Proceedings* when published. On three of the six days, simultaneous sessions were held in the auditoriums of the Instituto and Palacio. Similar translation services, projection equipment, etc., were made available in each location. A typical presentation is shown above—the session on Navigation and Guidance at the Instituto, with the head of the U.S.S.R. delegation, Dr. A. A. Dorodnitsyn, in the chair and with A. M. A. Majendie, of London, presenting his paper on "Safety in Automatic Flight Control."

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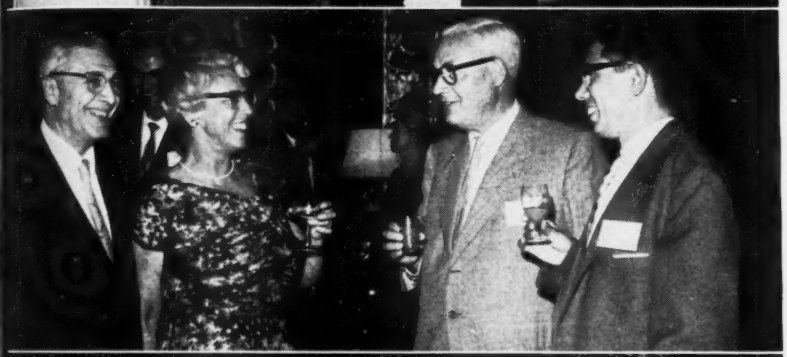
SOCIAL EVENTS

Our hosts spared no effort to make life in Madrid agreeable. The official Air Ministry reception, the Mayor's Reception and Concert, and the magnificent exhibition of Flamenco and folk dancing at Parque Florida sponsored by the Asociación Espanola de Ingenieros Aeronáuticos will be long remembered. In addition to such scheduled events, no delegate lacked for advice and assistance in making his own plans for shopping, entertainment, or travel. The traditional Spanish hospitality was in evidence everywhere, and even language differences proved little bar to mutual understanding.



The official group at the Air Ministry includes General José Rodríguez y Díaz de Lecea, Minister of Air, Dr. von Kármán, Mme. Talbot, June Merker (AGARD), and Dr. Frank Wattendorf.

Dr. and Mrs. W. B. Klemperer (Douglas), Professor H. J. van der Maas and H. Wittenberg (Netherlands).

Dr. E. R. Sharp (NASA), Dr. Stark Draper (MIT), and Dr. Manfred Rauscher (Federal Polytechnic Institute, Switzerland).

East meets West at the Mayor's Reception—Dr. and Mrs. Hoff accompanied by Ying-Nien Yu (Sandberg-Serrell Corp.) on the left and Professor Chih-Bing Ling (Tai-Wan University, Formosa) on the right.

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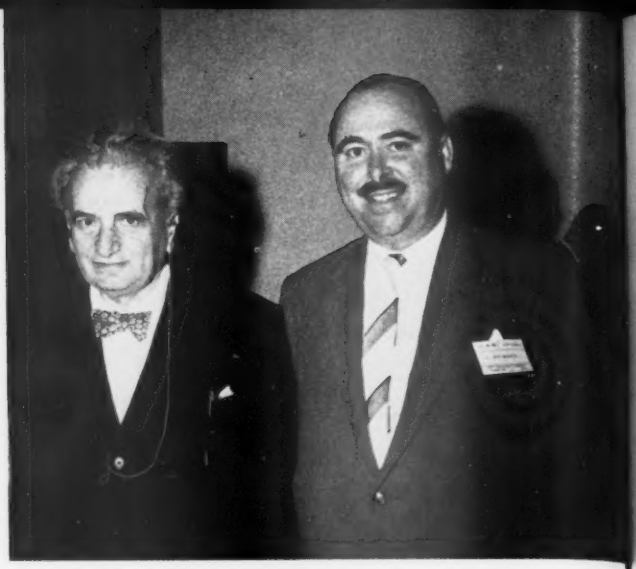
CONGRESS BUSINESS



Future Plans

During the week, the Provisional Council met on several occasions and took two important steps bearing on the future of ICAS. First, it was agreed that the term "provisional" should be dropped and that the present Council should be expanded by the addition of three new members—Belgium, Brazil, and Japan. Second, after discussion, it was decided that the next Congress should be held the week of September 12, 1960, at Zurich, Switzerland—with Stockholm, Sweden, as the probable locale for the Congress of 1962. (Above, Richard Greinacher, Council Member, extends Switzerland's invitation for 1960 to Council President von Kármán.)

Staff Work

Colonel Rafael Calvo, Director General, Instituto Nacional de Técnica Aeronáutica, gave full and invaluable support to the Congress. Too much credit could not be given to Col. Antonio Pérez-Marín and his staff of assistants for the organization and smooth functioning of the physical arrangements at the meetings and at the several social events. Much of the preliminary spade work on programs, papers, and discussions was done by the Secretariat under the direction of Robert R. Dexter, IAS Secretary. To June Merker of AGARD (who also represents the ICAS Secretariat in Europe) goes credit for assembling and organizing the corps of translators for the Congress. Joseph J. Maitan, IAS Controller, and Marjorie Rodé, Executive Assistant to the IAS Director, were on hand in Madrid (with Mr. Dexter) a week before the meeting opened to look after the complicated business arrangements connected with the delegates. Dr. A. M. Ballantyne, Secretary of The Royal Aeronautical Society, brought with him to Madrid several members of his staff who rendered invaluable assistance during the entire meeting. The success of the First Congress rested largely on the shoulders of the capable and devoted group pictured below. (Colonel Pérez-Marín stands in center between Marjorie Rodé and June Merker.)

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INTERNATIONAL COUNCIL OF THE AERONAUTICAL SCIENCES
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XUM

EDITORIAL

After Dr. Davidson's untimely death in Paris early this year, the following fragment was found among his papers. He felt very keenly about the subject. He evidently intended to expand on the theme at a later date. Because his ideas are entirely clear, we present his notes as they were found, without editorial embellishment.

The Scientific Approach

Blackstone Studios

Kenneth S. M. Davidson, 1898–1958

THE NATURAL SCIENCES, in their essence, are expressions of the human spirit, like music or literature. Man has always been curious about nature and the universe around him. He has always been led on, irresistibly, to explore things he does not understand. Often, in the process, he has discovered something quite different than he expected, and a new line of thought has been opened. So it has always been, and so it must inevitably go on. There is no other way known. The best scientists all agree on that. They agree, too, that if science is to flourish the prime need is a healthy sense of free enquiry. It is not that scientists consciously balk at restraints more than anyone else. It is simply that they stop functioning under restraints. The only choice one has is to give them their heads and get what they can give, or hold them on a rein and not get anything.

There is nothing new in this. It was understood in a groping way when Charles II of England founded the Royal Society in the 1600's. It was well understood in the German universities before the First World War. It is thoroughly understood by a great many people today in all parts of the world. Furthermore, there is a great deal more science of high caliber being done today than ever before in history. Why, then, should there be so much talk about it at this precise time?

One straightforward reason is clear enough. The influence of scientific discoveries on military affairs has been growing at a prodigious rate since the early days of the Second World War. At the same time, military affairs have continued to have an urgency about them and have been drawing very heavily on the accumulated background of scientific knowledge. Most scientists foresaw at the end of the war that something ought to be done to ensure a continuing supply of new knowledge. A little was done. Now there is concern that it was not enough.

But this does not go to the heart of the matter. There has even been talk of "crash programs" to make up for lost time. There is no such thing as a crash program in science. Science is a habit of mind, a sensitive awareness of the physical world which, with enough hard work now and then, leads to new concepts or new combinations of old concepts. When crash programs have produced startling practical results, they have been programs to exploit what was known or nearly known, not to discover the unknown. The groundwork of science was already well laid before they were started. This is true of radar, synthetic rubber, atom bombs, penicillin, in fact of the whole list. The rate of scientific discovery can surely be accelerated by bringing to bear a greater number of trained minds. It is certain that they exist potentially, but it takes time to train them. Some say a generation, beginning now. It might be done in that time, certainly not in less. It will not be done at all without deep understanding of the nature of the problem and a measure of patience. It can be nurtured, like all things of the spirit. It cannot be forced.

This may be a hard lesson. But the stakes are high.

Scientists are as much alive as any other group to the needs of the world. They know the urgency of expanding the scientific community of the free world. They have been preaching it. Now they want to make sure it is realized.

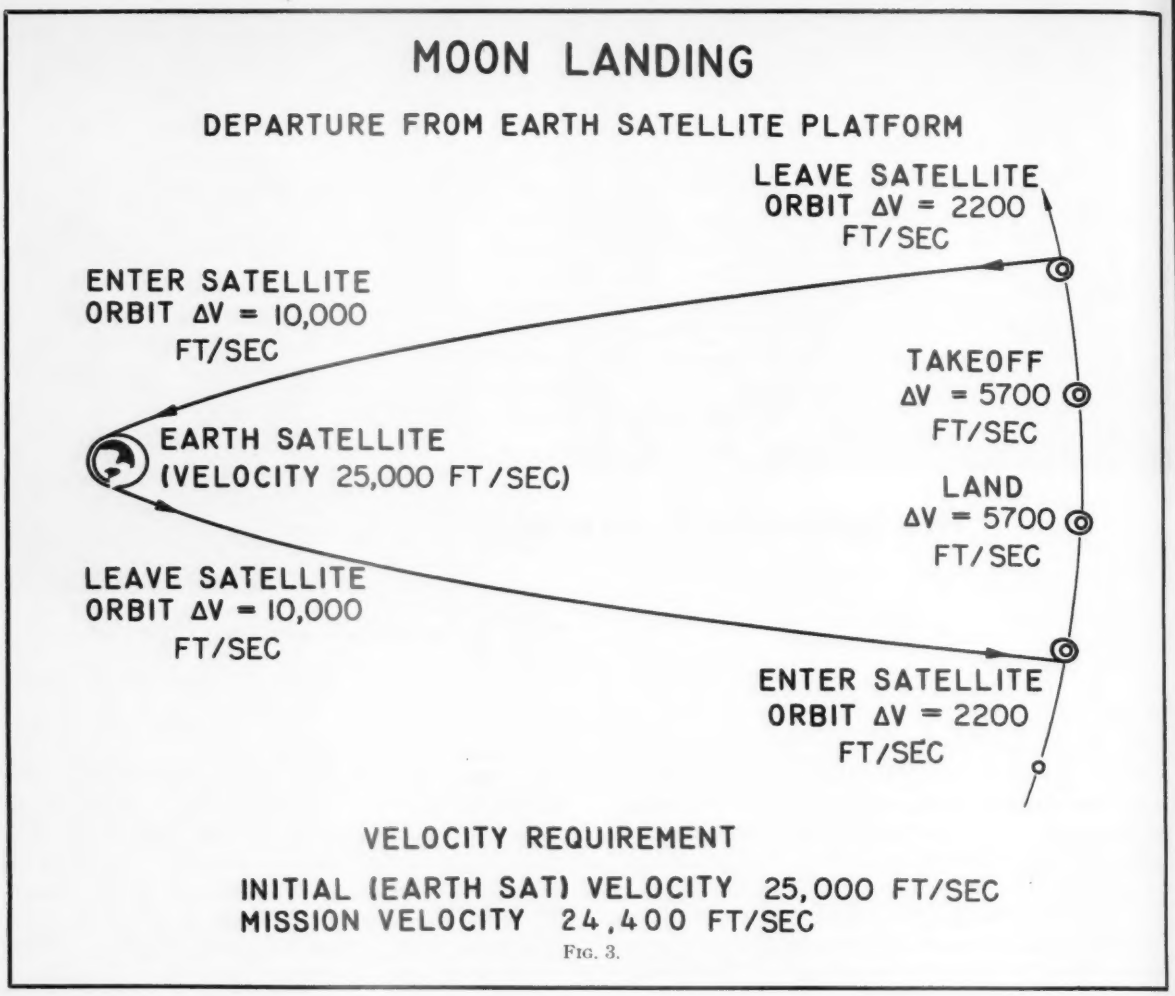
MOON LANDING
DEPARTURE FROM EARTH SATELLITE PLATFORM
LEAVE SATELLITE ORBIT ΔV = 2200 FT/SEC
ENTER SATELLITE ORBIT ΔV = 10,000 FT/SEC
TAKEOFF ΔV = 5700 FT/SEC
EARTH SATELLITE (VELOCITY 25,000 FT/SEC)
LAND ΔV = 5700 FT/SEC
LEAVE SATELLITE ORBIT ΔV = 10,000 FT/SEC
ENTER SATELLITE ORBIT ΔV = 2200 FT/SEC
VELOCITY REQUIREMENT
INITIAL (EARTH SAT) VELOCITY 25,000 FT/SEC
MISSION VELOCITY 24,400 FT/SEC

FIG. 3.

THE SUCCESSES of the Russian Sputniks and of our Explorers and Vanguard make the great potentialities of rocket propulsion clear to everyone. Much has been written and spoken about the real and bright prospects of manned space flight in the near future. There is, however, a big step between tossing a small payload into a satellite orbit and manned flight into outer space. A step in this direction will occur when the X15, now under construction, will carry its pilot higher and faster than anyone has gone before and subjects him to some of the problems of a safe return to earth.

In the following discussion, the velocity requirements for several missions will be given. Propulsion by various rocket methods will be described briefly with more detail on high-energy chemical rockets. The coverage of so broad a field in a single paper can serve as only an introduction to the subject.

VELOCITY REQUIREMENTS

Satellite velocity requirements are shown by Fig. 1. The curves are based on circular orbits. The satellite velocity is, of course, that velocity where the centrifugal force balances the gravitational pull. This velocity is tangent to the earth's surface.

A typical satellite trajectory consists of a vertical take-off and a curved flight that becomes tangent to the desired satellite orbit. One or more stages of boost and a coasting period usually are needed to reach the orbit

"Although propulsion is only one of the many problems facing the space traveler, it holds the key to his success. Historically, it seems that flight propulsion methods almost always lag behind the development of suitable vehicles, and space flight is no exception."

Rocket Propulsion Requirements for SATELLITES AND MOON MISSIONS

John L. Sloop

Lewis Research Center, NASA

tangent, and one or more stages are needed to accelerate the payload to the velocity required for the desired orbit. The orbits of the several earth satellites are ellipses.

A moon circumnavigation, as given by Ehricke and Gamow,[1] is shown by Fig. 2. If a vehicle is launched to take advantage of the earth's rotation, a velocity of 35,000 ft./sec. is required to put it in orbit to the moon. With proper guidance and timing with respect to the moon's orbit, the vehicle can approach the moon and swing around it. Relative positions of the vehicle and moon can be traced by the corresponding numbers on the two orbits. If it is desired to put the payload in an earth satellite orbit on its approach to the earth, the vehicle must be decelerated by 10,000 ft./sec. This can be done by applying reverse rocket propulsion, an expensive way, or by skimming through a portion of the earth's atmosphere and using friction with the air to slow down the vehicle. This must be done carefully to prevent overheating and requires several passes about the earth. Eggers of the NASA Ames laboratory has described this method of atmosphere braking.

A velocity budget for a moon satellite and landing, with departure from an earth satellite platform, is shown by Fig. 3. The velocity needed to leave the earth satellite platform and head for the moon is about 10,000 ft./sec. As the moon is approached, a deceleration of 2,200 ft./sec. is needed to swing into a moon satellite orbit.

An additional velocity requirement of 5,700 ft./sec. deceleration is needed for a "soft landing," and this

Condensed and revised from a paper of the same title presented before the IAS Washington Section, Feb. 11, 1958.

Mr. Sloop is Chief, Rocket Engines Branch.

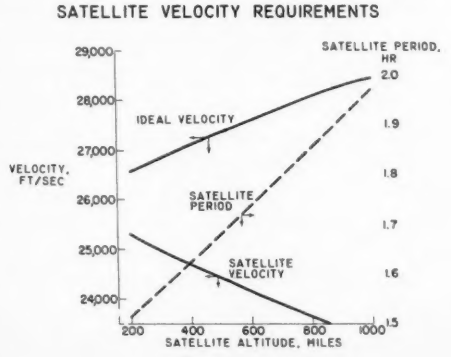

FIG. 1.

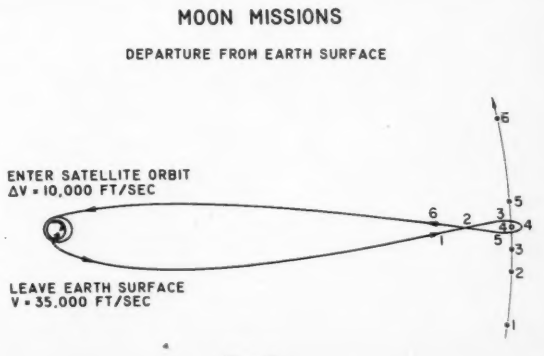

FIG. 2.

might be quite soft if the dust has much depth. The rocket exhaust will raise considerable dust—which could be a serious problem to the moon pioneer or his mate in a hovering ship.

The take-off from the moon's surface to rendezvous with the circling mother ship requires 5,700 ft./sec. acceleration, and, if all is well, the pioneers can accelerate another 2,200 ft./sec. and head back to earth, as previously described.

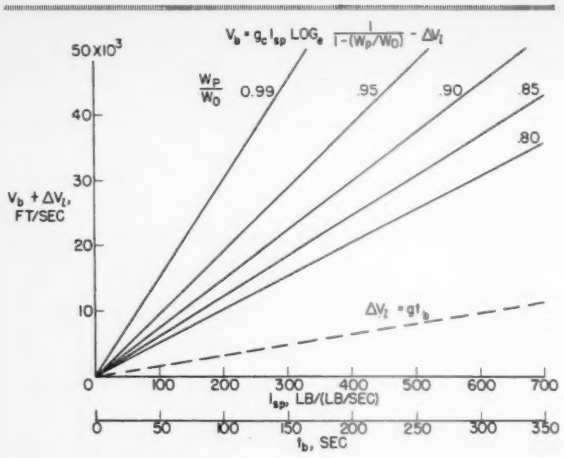

FIG. 4. Velocity equation.

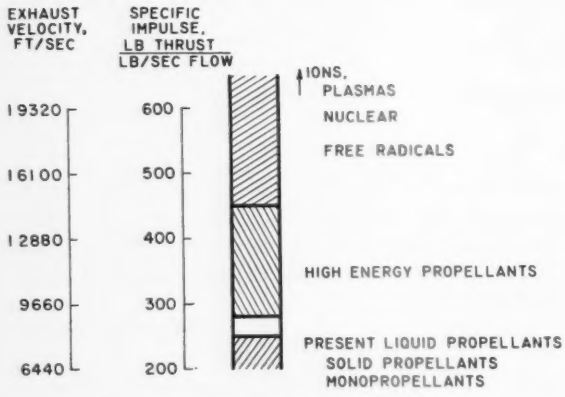

FIG. 5. Propellant performance spectrum.

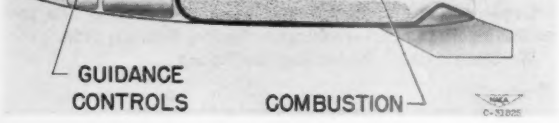

FIG. 6. Solid propellant rocket.

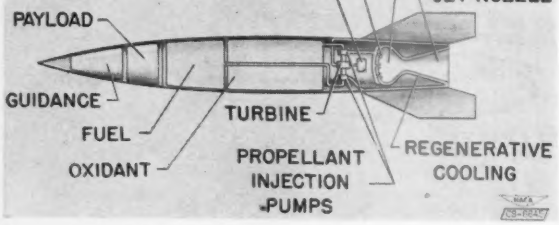

FIG. 7. Liquid propellant rocket.

VELOCITY OF A MISSILE

The velocity of a missile can be determined from the equation shown and plotted in Fig. 4. V_b is missile velocity at burnout, ft./sec.; g_c is the gravitational constant 32.2 ft./sec.^{2}; I_{sp} is specific impulse, lbs. thrust/(lbs./sec.); W_p is propellant weight, lbs.; W_0 is gross weight, lbs.; and ΔV_l represents the velocity losses from drag and gravitational pull. A plot of this equation shows the effect of the principal variables, specific impulse, and mass ratio (propellant/gross weight). The dashed curve represents the velocity loss from gravitational pull if the flight is vertical, which is simply the acceleration of gravity times the burning time t_b. (For other vehicle orientations, multiply by the sine of the angle of the vehicle with respect to the earth.)

As an example of the effect of the principal variables, consider a vehicle with a specific impulse of 200, a mass ratio of 0.80, and a burning time of 100 sec. The loss-free velocity is 10,000 ft./sec. and the velocity loss is a maximum of 3,000, leaving a net velocity of 7,000 ft./sec. Suppose a second vehicle had a specific impulse of 400 and a mass ratio of 0.9. Its loss-free velocity is 30,000 ft./sec. If the burning time is again 100 sec., the maximum velocity loss is 3,000 ft./sec., leaving a net velocity of 27,000 ft./sec. A gain in specific impulse of near this order can be obtained with high-energy propellants and large expansion ratios. The mass ratio of 0.9 is hard to come by but is possible with good design. Of course, such a mass ratio means that all the hardware, guidance, structure, tanks, controls, engines, and payload combined are only 10 per cent of the gross weight. The higher mass ratios are plotted for academic interest.

SPECIFIC IMPULSE SPECTRUM

All rockets produce thrust by accelerating a propellant. The index of merit of a rocket is the specific impulse, which is the thrust produced per pound per second of propellant flow. This is sometimes expressed in terms of exhaust velocity, which is related to specific impulse by the gravitational constant 32.2 ft./sec. squared.

Two major factors determine specific impulse: (1) the ratio of gas temperature to average gas molecular weight and (2) the pressure ratio through which the gases are expanded from the combustion chamber through the nozzle to the atmosphere. The first factor

is a function of the propellant combination; the second, of engine design.

The importance of using light propellants is often overlooked. For example, suppose we have a reaction with a temperature of 9,000°R. and a molecular weight of 18. The quotient is 500, which can be equaled by heating hydrogen to 1,000°R. Obviously, very heavy atoms or molecules are not desirable in the exhaust gas. Rocket nozzles designed for large pressure ratio expansion at altitude produce about 25 per cent more thrust than nozzles designed for expansion to sea-level pressure, other factors being equal.

Fig. 5 shows a propellant performance spectrum, with scales of specific impulse and exhaust velocity. Present liquids, solids, and monopropellants range in specific impulse from below 200 to about 250. Above them is a region of high-energy chemical propellants. Above them are free radicals,[2] nuclear propulsion, and propulsion by plasmas, ions, and photons.

Rocket Propulsion Methods

Solid Propellant Rockets

The solid propellant rocket was the first type of rocket produced and is finding increasing use today. A typical solid propellant rocket is shown by Fig. 6. The solid propellant, with a hollow center, is placed in a case to which the nozzle is attached. The propellant is ignited by a pyrotechnic, and burning takes place from the inner surface outward. This insulates the outer case until the last moment of burning. There are many compounds used in solid propellants, among them are nitrocellulose, nitroglycerin, and ammonium perchlorate. The specific impulse values of solids range from below 200 to 250 and perhaps higher.

Liquid Propellant Rockets

A typical liquid propellant rocket is shown by Fig. 7. The fuel and oxidant flow from the tanks to centrifugal pumps which boost the pressure. From there the oxidant flows through valves to the injector, where it is sprayed into the combustion chamber. The fuel is usually used as a coolant by passing it through passages in the nozzle and combustion chamber. From there it reaches the injector and is sprayed into the combustor, where it mixes and burns with the oxidant. The hot gases expand through the nozzle to produce thrust.

Fig. 8 shows the performance of present propellants based on a chamber pressure of 300 psia and on the assumption that the gas expands to sea-level pressure without change in composition (frozen expansion).

High-energy propellants are shown by Fig. 9. Highest performance is obtained with hydrogen as a fuel.

Thermonuclear Rockets

A nuclear rocket (Fig. 10) carries a single propellant tank of some light propellant such as hydrogen. The propellant is pumped to a reactor which heats it, and expansion takes place through the nozzle as in other rockets.

The performance of heated hydrogen as a function of temperature is shown by Fig. 11. The curves are for chamber pressures of 300 and 1,200 psia and expanding to sea-level pressure; lower pressures could be used for space vehicles. (A number of papers have been written on nuclear rockets—e.g., references 3, 4, and 5.)

Electric Rockets

A number of methods of obtaining very high specific impulses by using electric or solar power are being studied. One of these, as shown by Fig. 12, is the arc jet, where the working fluid is heated by an electric arc. It consists of a positive electrode in the back of the chamber with the nozzle as the negative electrode. A nuclear-electric system furnishes the power to start and maintain an arc between the electrodes. A light propellant, such as hydrogen, is first used to cool the chamber and then is heated by the arc to a high temperature, after which it is expanded through the nozzle to produce thrust. Specific impulses on the order of 1,500 are possible with this system. Obvious disad-

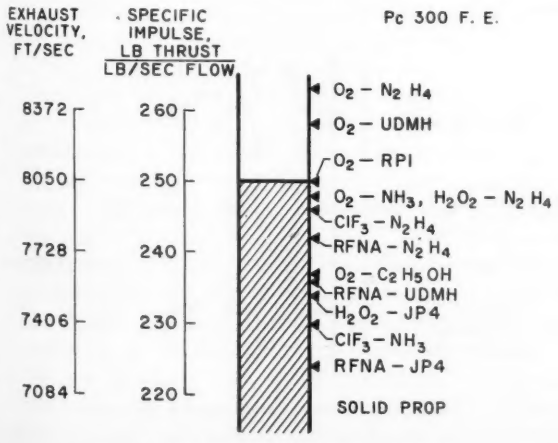

FIG. 8. Performance of present propellants.

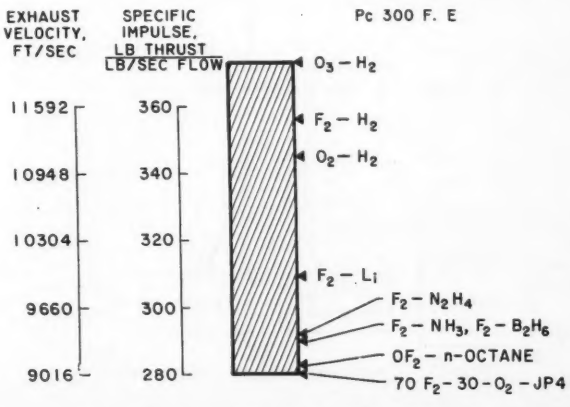

FIG. 9. Performance of high-energy propellants.

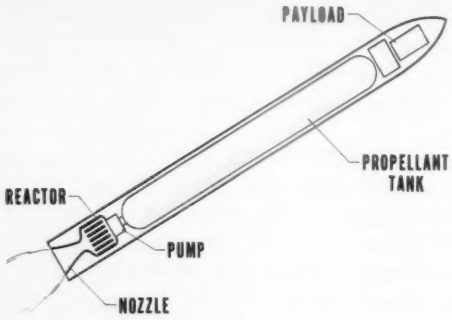

FIG. 10. Nuclear rocket.

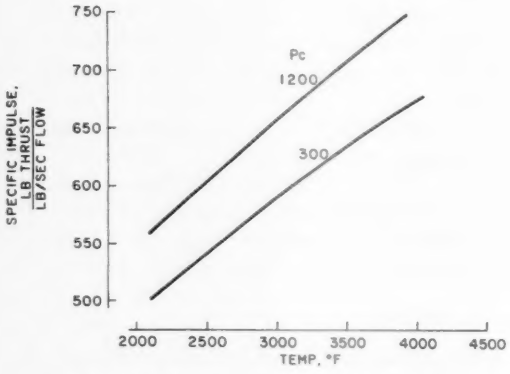

FIG. 11. Performance of heated hydrogen.

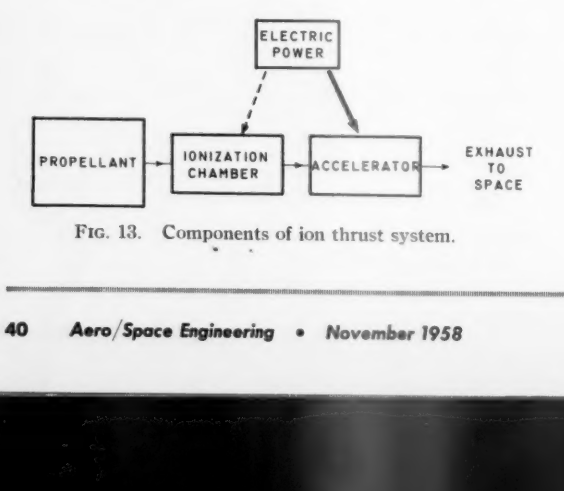

FIG. 12. Arc-jet propulsion system.

FIG. 13. Components of ion thrust system.

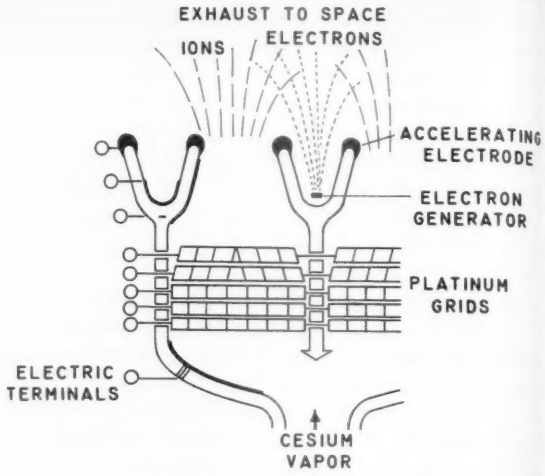

FIG. 14. Ion and electron source (Stuhlinger).

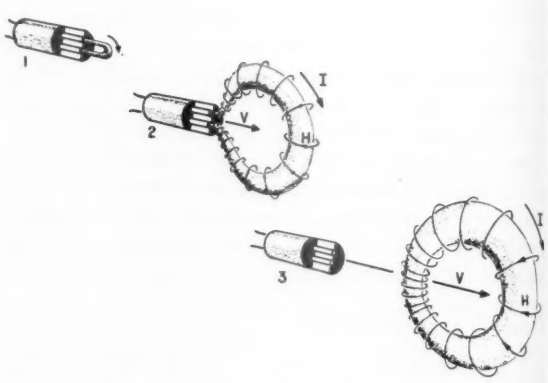

FIG. 15. Bostick's plasma accelerator.

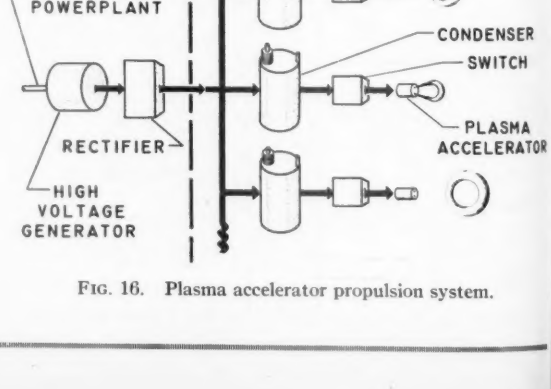

FIG. 16. Plasma accelerator propulsion system.

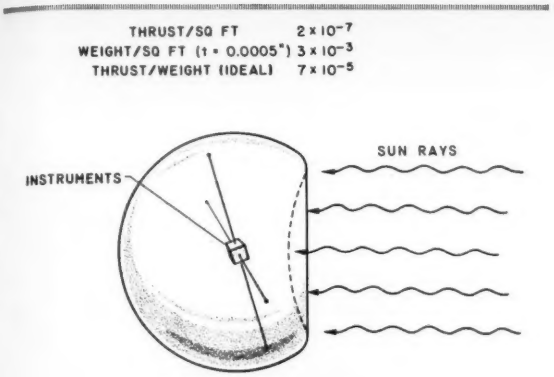

FIG. 17. Photon sail.

vantages of such a method are high electrode consumption and high heat transfer rates to the nozzles. Indicated on the diagram is an auxiliary recirculating cooling system for the electrode part of the nozzle if the heat load is too great for the propellant.

The components of an ion thrust system are shown in Fig. 13. Again a nuclear source of electric power is considered. The propellant is ionized, then accelerated electrostatically and ejected to produce a small thrust. Both positive ions and electrons must be ejected or else a space charge builds up that stops the flow of ions. Stuhlinger[6] has suggested using alkali metals such as cesium, rubidium, and potassium because these can be ionized readily by a hot platinum surface. Fig. 14 shows his ion and electron source and thrust chambers. It is desirable to have as large a current density as possible, but this is limited by external space charge. According to the Shottky-Langmuir space charge law, the current density is inversely proportional to the square of the distance from the accelerator exit to the point of neutralization. This distance should be kept to a fraction of an inch to keep ion jet areas within reason.

A plasma accelerator is shown by Fig. 15. Plasma is ionized gas with a neutral charge, and the accelerator was suggested by W. H. Bostick.[7] It consists of two electrodes in an insulator. If an arc discharges across the electrodes, a magnetic field develops which reacts with the current flow to produce a force perpendicular to both. Since the field is stronger on the inner surface than the outer, a net force forward is developed as depicted in the figure. Specific impulses as high as 20,000 can be obtained. A propulsion system using this accelerator is shown in Fig. 16. A nuclear power plant with a high-voltage generator and rectifier supply the electric potential and energy. Condensers are charged, then discharged through suitable switches to produce the arc across the accelerator electrodes. Many accelerators in parallel and operating in rapid succession are needed to produce a small thrust.

The ultimate in high specific impulse would be the goal of using a photon sail shown by Fig. 17. Photons from the sun are reflected from the mirrored surface of the huge balloon-sail. Thrusts would be on the order of 2×10^{-7} lbs./sq.ft., but specific impulse would be infinite. Some sort of control device would be needed to shield the mirror when the sun was in the wrong direction.

The various methods of propulsion are compared in Fig. 18. The chemical rockets range in specific impulse from 300 to 1,000 if free radicals are used and the engines give from 50 to 80 lbs. thrust per pound of engine weight. Initial vehicle acceleration with these engines ranges between 1.2 to 1.5 and sometimes higher. The nuclear-thermal-rocket can be considered in this same general category. The nuclear-electric rockets are characterized by very high specific impulses—up to 20,000—and also by high engine weights or low thrust per pound of engine weight. Their massiveness means that vehicle acceleration will be extremely low. Propulsion by solar energy falls into this same general category.[8]

Different propulsion methods will be used for different phases of space flight. Chemical and nuclear propulsion will be used for establishing earth satellites and building up supplies for a space mission. Both types are also useful for certain space missions as well. The electric systems look promising for extended solar journeys where mass consumption must be minimized. All of them involve a large number of problems that must be solved before manned space travel becomes a reality. Let us examine briefly the problems of using one of these—high-energy chemical rockets.

Problems in High-Energy Chemical Rockets

The major components in liquid propellant propulsion are tanks, pumping, thrust chamber, and controls. Tanks must be light yet strong enough to withstand the design pressure and forces imposed by the engine thrust and flight through the atmosphere. The propellants must be pumped to the engine, and this can be done either by pressurizing the tanks or by using turbine-driven pumps. Pressurization is limited to modest pressures, or else tank weight and pressurizing gas requirements become too high. Pumping involves the complication of rotating machinery with problems of gas generation for the turbine, pump cavitation, turbine-pump speed matching, and lubrication

ENERGY SOURCE	SPECIFIC IMPULSE, LB/LB/SEC	JET VELOCITY, FT/SEC	SPECIFIC WT LB THRUST / LB ENG	VEHICLE ACCELERATION, G
CHEMICAL				
SOLID	300	9,700	50-80	1.2-1.5
LIQUID	300	9,700		
HIGH ENERGY LIQUIDS	460	15,000		
FREE RADICALS	1,000	32,000		
NUCLEAR-THERMAL	1,000	32,000	---------	1.2-1.5
NUCLEAR-ELECTRIC				
ARC	1,500†	48,000	0.05-0.0015	0.0005
ION	20,000	640,000	0.0005-0.00005	0.00001
PLASMA	20,000	640,000	---------	-----
SOLAR				
THERMAL	500	16,000	0.5	0.01
PHOTON	∞	∞	0.00007	-----

FIG. 18. Comparison of rocket propulsion systems (approximate values, space flight).

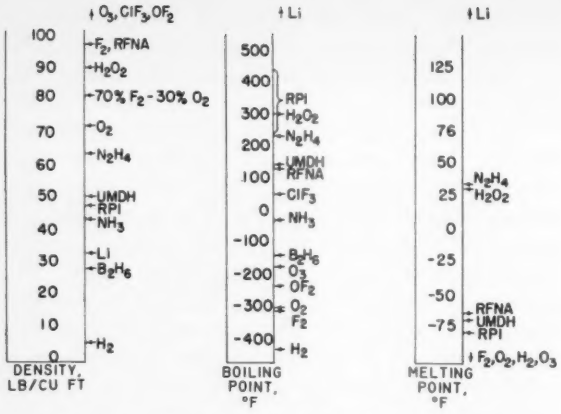

FIG. 19. Physical properties of fuels and oxidants.

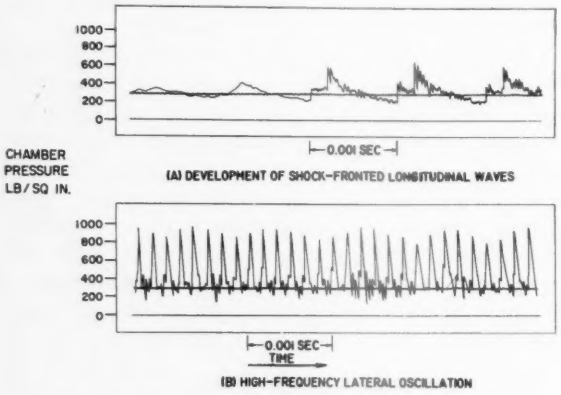

FIG. 23. Pressure records in screaming rocket.

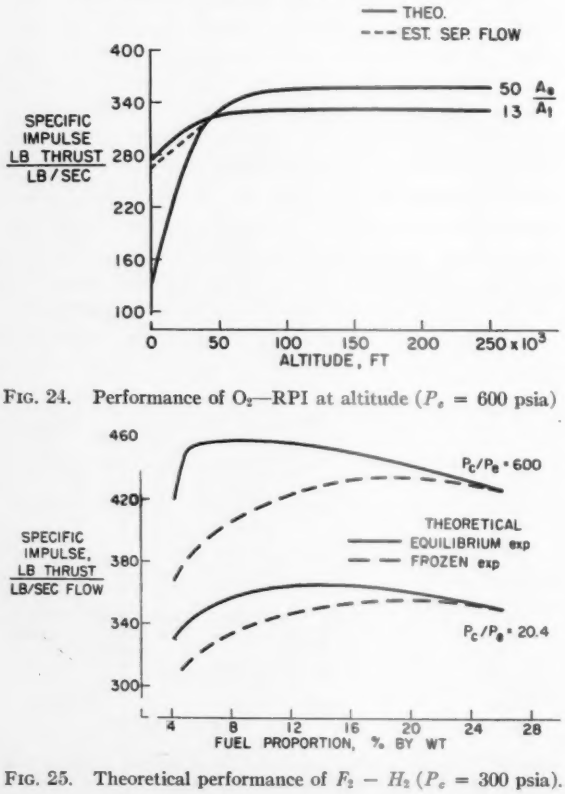

FIG. 24. Performance of O_2—RPI at altitude (P_e = 600 psia)

FIG. 25. Theoretical performance of $F_2 - H_2$ (P_e = 300 psia).

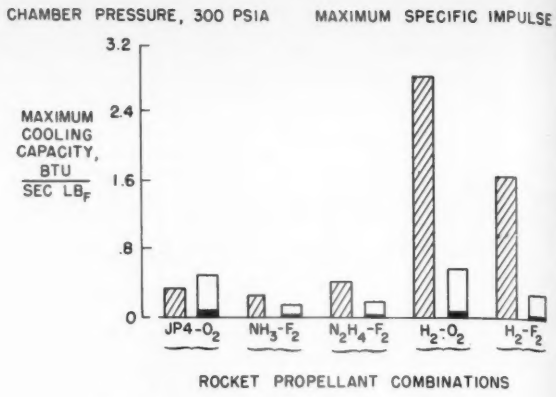

FIG. 20. Cooling capacities of propellants.

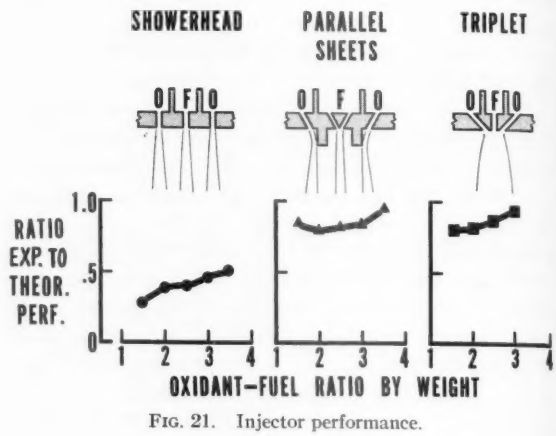

FIG. 21. Injector performance.

FIG. 22. Combustion oscillation modes.

and sealing problems. The thrust chamber has problems of propellant injection, chamber and nozzle cooling, starting, cooling, and nozzle design for best weight, cooling, size, and performance compromises. Controls must start and stop the engine smoothly and quickly, balance the propellant flows so the tank of one is not exhausted before the other, and vary the thrust vector as demanded by the guidance system.

Many of the chemical rocket engine problems arise from the nature of the propellants used; indeed, this is so great an influence that it should be considered first. Desirable propellant characteristics are high specific impulse, high density, high specific heat, thermal stability, high reaction rate, low vapor pressure, low freezing point, nontoxicity, noncorrosiveness, high availability, and low cost. The value of high specific impulse has already been discussed. A high density aids in reducing tank weight. High specific heat and thermal stability are needed for the propellants used for coolants or where high tank temperatures are reached from air friction. High reaction rate means less combustion volume and quick, reliable starting. Low vapor pressure under storage, low freezing point, low toxicity, and low corrosiveness are desirable storage and handling characteristics. Good availability and low cost are the crowning touch to the list.

One need not be a chemist to realize that there is no ideal propellant that meets all these requirements or even a part of them. For example, consider the physical properties of density, boiling point, and melting point as shown by Fig. 19. The density of many of the propellants is fairly good with one big exception—hydrogen—which has a density about 1/10 that of RPI (a kerosene-type fuel). The boiling points of the high-energy oxidants—oxygen, fluorine, and ozone—are extremely low, as is that of hydrogen; thus the rocket designer is faced with using cryogenic fluids. The melting points of most of the propellants are good except for hydrazine, hydrogen peroxide, and lithium.

Other propellant properties are equally difficult to cope with. Fluorine, for example, is highly toxic and reactive. Extreme care must be used to keep all organic contaminants out of systems containing fluorine. Exhaust gases containing hydrogen fluoride are also toxic and bring up many ground handling problems.

Propellants must be used to cool the engine prior to combustion; the cooling capacities of several propellants for several high-energy propellants are shown by Fig. 20. The index of comparison is the heat-absorption capacity, in B.t.u. per second, for each pound of engine thrust, which is one way of lumping together the specific heat, allowable temperature rise, and the proportionate amount of propellant flow at maximum specific impulse. It can be seen that hydrogen is attractive as a coolant.

Another problem in liquid propellant rockets is the proper injection of the reactants into the combustion chamber to get smooth, efficient combustion. Again, the physical and chemical properties of the propellants play a prominent role. For example, Fig. 21 shows injector performance for a combination where the fuel requires appreciable heat for vaporization and the reaction begins in the vapor phase. Injection through straight holes to give parallel jets gave the lowest performance; the injection processes where the fuel was atomized well, as in parallel sheets and triplet patterns, gave considerably higher performances. Fuels with different physical and chemical properties would respond differently[9] so the search proceeds for the injection method that is best from considerations of performance, cooling, weight, combustion stability, and ease of fabrication.

Rocket-engine developers must frequently wrestle with an insidious problem known variously as combustion oscillations, combustion stability, screaming, or chugging. The higher frequency types act in a manner similar to sound waves. That is, they may bounce back and forth longitudinally (Fig. 22), or in and out radially, or across the chamber in transverse modes. These oscillations are vicious because they can increase the heat transfer and chamber pressure several-fold and strain beyond limit the cooling capacity or strength of the chamber. Fig. 23 shows pressure records in a screaming rocket. The upper record shows the development of shock-fronted longitudinal waves and the lower one lateral oscillations. Note the threefold increase in chamber pressure which is accompanied by a similar increase in heat transfer. Many papers have been written on the cause of these oscillations and a few on the cure. It is known that the injection process and the chemical reactivity of the propellants, as well as chamber geometry, are factors, but more information is needed to enable an engine designer to avoid this problem.

A problem of nozzle design is illustrated by Fig. 24. Specific impulse as a function of altitude is shown for two nozzle designs, one for a ratio of exit area to throat area of 13 and the other 50. Assume that the rocket operates from sea level to 100,000 ft. altitude or higher. If the smaller nozzle is chosen, a higher specific impulse is obtained at sea level, but performance is lower at altitude than with the larger nozzle. The larger nozzle has quite low performance, theoretically, at sea level but a higher performance at altitude. The low performance of the larger nozzle at sea level is caused by extremely large gas overexpansion. Fortunately the real gas frequently refuses to overexpand this much and separates from the wall. This effectively cuts down the area ratio, and performance of the larger nozzle may follow the dashed curve. This indicates that a high area ratio nozzle is desirable, but the designer must also reckon with increased weight, size, more surface to cool, and increased moments on the thrust vector controls.

A problem arising from the gas expansion process is shown by Fig. 25. Theoretical values of specific impulse as a function of fuel proportions are shown for fluorine-hydrogen.[10] The two lower curves are for an expansion ratio from chamber to nozzle exit pressure of 20.4 and the upper curves for a ratio of 600.

FIG. 26. High-energy propellant rocket laboratory.

The solid curves are based on the assumption that the composition of the combustion gas mixture adjusts instantaneously to the local values of pressure and temperature in the nozzle. This is called equilibrium expansion. The dashed curves are for the assumption that the composition of the gas mixture does not change as it rapidly expands through the nozzle. This is called frozen expansion. The true expansion must lie somewhere in between and may vary depending upon the individual atomic and molecular species in the gas mixture. For many propellants these two theoretical curves are within a few per cent of each other. For hydrogen-fluorine, however, a major advantage is at stake. Rocket engines designed for upper stage or space applications will have as large an expansion ratio as practical. If the real gas expansion follows the equilibrium curve for an expansion ratio of 600, very high specific impulse values are possible with very low amounts of hydrogen. This cuts drastically the tank volumes needed for this ultralow density fuel (provided the engine can be cooled with the lesser amount of hydrogen). If, on the other hand, the real gas expansion follows the frozen expansion curves, high specific impulse values will require almost three times as much hydrogen or three times the tank volume. Research is needed to answer this question and to seek solutions to the other problems cited.

NASA High-Energy Research Facilities

The NACA (now NASA) had long recognized the potential value of high-energy propellants for satellite and space travel applications and constructed unique facilities for their study. Fig. 26 shows a view of a new high-energy facility put into operation prior to the Sputniks. Engines using high-energy propellants and developing thrusts as high as 20,000 lbs. can be studied under safe operating conditions.

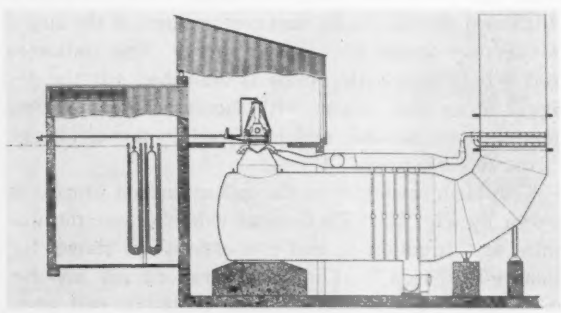

FIG. 27. Sectional view of rocket engine research facility.

Unique features of the facility are the silencing of the rocket roar and the handling of the exhaust fumes by water scrubbing. Fig. 27 is a sectional view showing the system. The tanks to the left are high-pressure vessels with the oxidant system immersed completely in liquid nitrogen. The engine is shown at one end of the scrubber ell. It fires vertically downward. The hot 6,000° to 8,000°F. exhaust, roaring out at velocities over 10,000 ft./sec., strikes water flowing from spokes protruding into the jet. In a twinkling, the gas is cooled to below 300° and a whisper of its former self. The operators must rely on visual aids and instrumentation to know that the engine is running. The gas then flows past a multitude of water sprays in the horizontal section which absorb the hydrogen fluoride. The hydrogen fluoride in the waste water is converted to calcium fluoride and hauled away to an industrial waste dump.

Major Tasks

The problems facing manned satellites and space travel can be summarized as follows:

(1) We must develop lightweight, efficient engines using chemical, nuclear, and electric energy.

(2) We must learn how to make very lightweight tanks and structures because every pound carried represents a large investment in energy.

(3) We must learn how to keep propellants for long periods of time for propulsion requirements days after take-off.

(4) We must make giant advances in engine and systems reliability.

(5) We must develop very accurate guidance to fly exact orbits timed carefully with respect to the earth or planet we wish to reach and maintain reliable communication with the earth.

(6) Men must learn how to live safely in the dangers of outer space and keep alert during confinement for many days of flight.

(7) Men must learn how to return safely to earth.

Although propulsion is only one of the many problems facing the space traveler, it holds the key to his success. Historically, it seems that flight propulsion methods almost always lag behind the development of suitable vehicles, and space flight is no exception.

A vigorous and imaginative research program will put and keep the United States in the lead in solving these problems. The NASA is part of a national team hard at work on these tasks.

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(*Continued on page 50*)

High-energy fuels and marked improvements in aerodynamic efficiency make possible supersonic commercial transports at take-off weights comparable to present jet transport designs.

Some Effects of High-Energy Fuels on Aircraft Performance

Abraham Hyatt
Department of the Navy

In the past 2 years, there have been a number of disclosures by the Department of Defense of a high activity in the field of the synthesis of high-energy fuels for aircraft. Obviously, important benefits must be possible from the use of such fuels. It is the purpose of this article to discuss the principal ways in which high-energy fuels might affect the weight, range, and performance of aircraft, commercial and military.

Aircraft air-breathing engines derive their power from the release of energy when aircraft fuels are burned in the presence of air. Normally, the energy or heat content of a fuel is expressed in B.t.u. per pound. The most commonly used aircraft fuels are the liquid hydrocarbon JP fuels, derived from petroleum crudes. The heat of combustion of such fuels is approximately 18,500 B.t.u./lb. A high-energy fuel, as used in this analysis, is defined as a fuel which has a significantly higher combustion heat per pound than the present aircraft fuels.

To illustrate the potential gains in aircraft performance that are possible from use of high-energy fuels, a hypothetical high-energy fuel is used. The fuel is assumed to have a heat content per pound 50 per cent greater than the liquid hydrocarbon fuels or 27,750 B.t.u./lb. All other characteristics of the fuel are assumed to be similar to or the same as present aircraft fuels, so that no changes in engine or airframe are required. These idealized conditions are used because the main objective of this paper is to treat the effect of increased heat content of fuels on aircraft performance

Principles Involved

Important improvements in aircraft performance that are possible with high-energy fuels (subsequently referred to as HEF) are best illustrated by a simple relationship and a series of graphical representations.

The total take-off weight W of an airplane will be subdivided into four major categories arbitrarily selected as structural weight S, power-plant weight E, fuel weight F, and payload P.

It is apparent, therefore, that $S + E + F + P = W$.

If the payload is known and the ratios of the other weights to the gross weight are given, then gross weight can be determined as follows:

$$W = \frac{P}{1 - (S/W) - (E/W) - (F/W)} \qquad (1)$$

Supposing now that the take-off weight or gross weight, used interchangeably, of an airplane is represented by a Pie diagram. Fig. 1(a) is such a representation for a JP fueled airplane. The sectors represent the four weight categories into which the airplane is divided. An allowance, for this example, of 25 per cent of the take-off weight is made for structure, 15 per cent for power plant, 45 per cent for fuel, and the payload is assumed to be 15,000 lbs. A substitution of these values in Eq. (1) yields

$$W = 15{,}000/(1 - 0.25 - 0.15 - 0.45) = 100{,}000 \text{ lbs.}$$

The fuel weight is, therefore, 45,000 lbs. This amount of fuel is necessary, presumably, to fly the mission profile of the airplane. Another way of expressing the

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The views expressed in this paper are those of the author and should not be construed as reflecting those of the Bureau of Aeronautics or the Navy Department at large.

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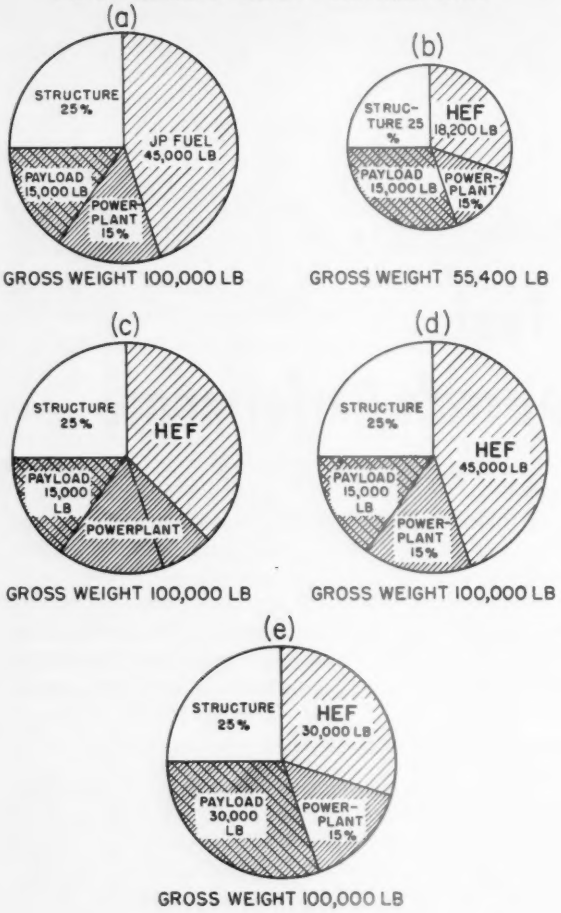
FIGURE 1
PIE DIAGRAMS OF WEIGHT DISTRIBUTIONS



same requirement is to say that so many B.t.u. are required to fly the mission profile. It follows then that a fuel which has more B.t.u. in every pound would need fewer pounds to fly the given mission.

The hypothetical HEF was assumed to have 27,750 B.t.u./lb. So, if the above airplane were fueled with HEF instead of JP fuel, it would need only (18,500/27,750) × 45,000 = 30,000 lbs. of fuel. The gross weight of the airplane would now be only 85,000 lbs. since the fuel weight was reduced from 45,000 to 30,000 lbs. Nothing else was changed to achieve the lower take-off weight of 85,000 lbs.

Since the take-off weight has now been reduced, it is reasonable to reduce the wing, for example, in proportion to the gross weight. In fact, it is approximately true to say that all the take-off weight of the airplane, except the payload, is reduced in some relation to the fuel load. By assuming that the *ratios* of structural and engine weights to gross weight remain the same even though the gross weight of the airplane is reduced from the initial 100,000 lbs., and using the known weight of HEF and payload, the gross weight becomes

$$W = (30{,}000 + 15{,}000)/(1 - 0.25 - 0.15)$$
$$= 75{,}000 \text{ lbs.}$$

A considerably reduced gross weight has been achieved because of fewer pounds of fuel and proportionately reduced fixed weights. It must be remembered, however, that this reduced take-off weight still carries in it the same total energy as was required for the 100,000-lb. airplane. Because the smaller airplane needs less energy to do the same job, some of the HEF can be eliminated. Again, it can be reasoned that less structural and power-plant weight will be needed to carry the lesser weight of fuel. By continuing to retain the percentages of these items constant, a new gross weight can be determined, and so on.

The general gain can be expressed by modifying Eq. (1). At equal values of radius, cruise speed, and L/D, the ratio of fuel to gross weight is given by

$$\left.\begin{aligned} F/W &= 1 - 10^{\,b \log_{10}[1-(F/W)_t]} \\ W &= \frac{P}{1 - (S/W) - (E/W) - \{1 - 10^{\,b \log_{10}[1-(F/W)_t]}\}} \end{aligned}\right\} \quad (2)$$

where

b = (B.t.u./lb. of JP)/(B.t.u./lb. of HEF)

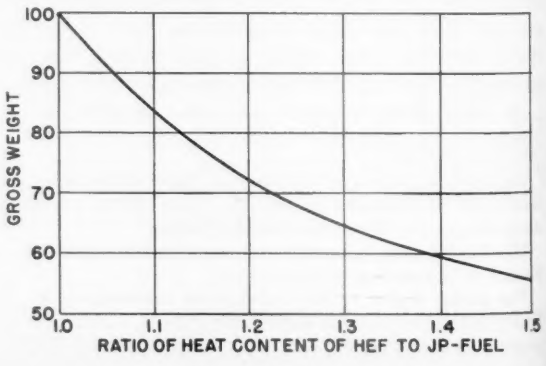
and $(F/W)_t$ = the ratio of fuel to gross weight for JP fuel. Therefore, the gross weight of the HEF airplane will be

$$W = \frac{15{,}000}{1 - 0.25 - 0.15 - [1 - 10^{0.67 \log_{10}(1-0.45)}]}$$
$$= 55{,}400 \text{ lbs.}$$

The initial gross weight of 100,000 has been reduced to approximately one half by using an HEF with a heat content of 50 per cent greater than JP fuel. Continuing the graphical analogy, Fig. 1(b) represents the lower gross weight airplane. It should be noted that the weight of fuel required is less than one half as much as the JP fueled airplane. For military purposes, the logistic advantage would be significant.

Only one value of heat of combustion of HEF has been discussed. Using Eq. (2) and the values from the above example, the effect on gross weight of varying the energy content of the HEF can be determined. A plot of the gross weight versus the ratio of heat energy

FIGURE 2
GROSS WEIGHT VS RATIO OF HEAT OF COMBUSTION



of HEF to JP is shown in Fig. 2. It is interesting to note that the reduction in weight is proportionately greater with the initial increases in heat content. In this example, the reduction in gross weight for the first 20 per cent increase in heat energy is nearly 63 per cent of the weight decrease in going all the way to a 50 per cent increase in heat energy.

The method of analysis used in the illustration is valid only when the ratios S/W and E/W are constant with changing W. Complete aerodynamic and engine similarity must also exist. In practical design situations, none of these conditions apply exactly. For comparative purposes, however, the method offers a reasonably close approximation.

Reduction in take-off weight is not the only manner in which the benefit from HEF can be used. In Fig. 1(c) a portion of the weight of fuel that was saved just by changing the energy content of the fuel has been added to the power-plant weight. The area of the circle and hence the total take-off weight is the same as in Fig. 1(a). Now, however, the added weight allowance for the power plant permits the use of larger engines. Increased engine size normally provides more thrust. With greater thrust, but no change in gross weight, a particular airplane will have higher speed, better rate of climb, more altitude, etc.

All of the difference in weight between the JP fuel and the HEF was not put into engine weight, and for a good reason. The larger engine needs more fuel or energy for every part of the mission. This extra amount of energy must be added to that required for airplane 1(a). Otherwise, airplane 1(c) could not fly as far, for example, as airplane 1(a). By properly balancing the division of weight between HEF and larger engines, airplane 1(c) can have more performance and still do the same mission as airplane 1(a).

Still a third manner of gaining a very large benefit from HEF is available. Airplane 1(a) carries 45,000 lbs. of JP fuel. The entire weight can be replaced by HEF, as shown in Fig. 1(d). Airplane 1(d) then will have 50 per cent more energy available than airplane 1(a). Everything else being equal, it is clear that airplane 1(d) can have a different mission profile. It can have a range at least 50 per cent greater than airplane 1(a). Or, if 1(a) and 1(d) are military aircraft, then the extra energy can be used to allow the HEF airplane a longer combat time.

Finally, the JP fuel in airplane 1(a) can be replaced by just enough HEF to perform the mission. The weight difference saved can be used to increase the payload significantly as shown by Fig. 1(e).

The above discussions have shown that the benefits from HEF relative to JP fuels can be used in any one of the following ways:

(1) Reduced gross weight to accomplish the same mission.

(2) Increased performance at the same gross weight.

(3) Increased range or combat time (for military aircraft) at the same gross weight.

(4) Increased payload at the same gross weight.

(5) Any combination of items 1 through 4.

Calculations for the above illustration of the principles involved have been greatly simplified. Now it is interesting to examine the results of more accurate and detailed studies. Both commercial and military jet aircraft applications were investigated. The results of the commercial aircraft studies will be discussed first.

Effects on Commercial Jet Transports

Commercial jet transport aircraft are now in the testing stage. In another year, the first regular airline operations are expected. An undesirable characteristic of jet-powered aircraft is their high proportion of fuel weight to take-off weight for reasonably long ranges. In some of the commercial jet transports now under construction, the fuel weight will exceed 40 per cent of the take-off weight. The greater the proportion of an airplane that is fuel, the more attractive will be the improvements possible from HEF. For these reasons it is interesting to analyze the possible gains in performance from HEF in commercial jet transports.

The direct objective of the analysis was to determine the variation of take-off weight with range for a series of cruise speeds. The selection of cruise speeds was arbitrary and they range from 500 knots, $M = 0.88$, to 1,725 knots, $M = 3.0$.

Two hypothetical HEF fuels were used. One was assumed to have 30 per cent more B.t.u./lb. than JP fuels and the other 50 per cent more B.t.u./lb. The weights versus range were computed for a series of JP fueled aircraft and for the same series with the two high-energy fuels.

Before discussing the results, some of the main assumptions and conditions that were used should be noted. In all cases, a constant payload equivalent to 144 passengers together with their requirements was used. Engines were selected to fit each speed category. They were not fully optimized for any of the designs but are believed to be close to the practical optimum at this time, especially in terms of engine specific weight and specific fuel consumption. Some typical values of these characteristics are shown in Table I. A typical percentage weight distribution for a 1,000 knot cruise

TABLE I
SOME TYPICAL VALUES OF ENGINE PERFORMANCE CHARACTERISTICS

CRUISE SPEED KNOTS	CRUISE ALT. FT.	POWER SETTING	JP-4 SPECIFIC FUEL CONS. LB/HR/LB	SPECIFIC WT. DRY* LB. WT. / LB THRUST
500	35,000	NORMAL CONTINUOUS	1.00	.50
750	55,000	WITH AB	1.60	.65
1000	55,000	WITH AB	1.60	.40
1725	65,000	WITH AB	2.00	4.35

*AT THE SPECIFIED ALTITUDES

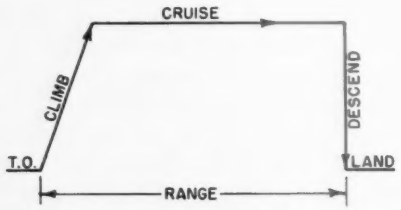
TABLE II

TYPICAL WEIGHT DISTRIBUTION FOR 1000 KNOT CRUISE SPEED AIRCRAFT

	PERCENT OF GROSS WEIGHT
PAYLOAD CREW PASSENGERS CARGO BAGGAGE FURNISHINGS ELECTRONICS EQUIPMENT INSTRUMENTS AIR CONDITIONING	16.0
STRUCTURE	25.0
POWER PLANT	19.0
FUEL	38.5
FUEL SYSTEM	1.5
TOTAL	100.00

FIGURE 3

TYPICAL FLIGHT PROFILE FOR TRANSPORT DESIGNS



ALLOWANCE FOR WARM-UP AND TAKE-OFF EQUALS 2% INITIAL GROSS WEIGHT

ALLOWANCE FOR RESERVES EQUALS FUEL TO REACH ALTERNATE FIELD 200 NAUTICAL MILES BEYOND DESTINATION PLUS 10% OF FUEL CONSUMED DURING CRUISE AND THE 200 N. MILES

IN ADDITION TO ALLOWANCES ABOVE THE FUEL CONSUMPTION IS ARBITRARILY INCREASED 5% THROUGHOUT MISSION

speed aircraft is shown in Table II. Adequate take-off thrust to be compatible with modern airport runways was provided. The flight profile with the allowances for reserve is shown in Fig. 3.

The aerodynamic efficiency that was applied is reflected by the values of maximum L/D versus speed that are shown in Fig. 4. The solid lines represent what is believed to be the present state of the art. In order to show the effects of improved aerodynamic efficiency, the basic values of L/D were arbitrarily increased by a factor of 1.5. The resultant values are shown by a dashed curve on Fig. 4. Additional calculations were made with the increased values of L/D, and the effects on gross weight and range will be discussed later.

The results of the computations are shown in Figs. 5(a), (b), and (c) and 6(a) and (b). The marked improvements from HEF in range or take-off weight are apparent. For example, entering Fig. 5(a) at a value of range of 3,500 nautical miles, more than adequate for a nonstop flight from New York to Paris, we can read the gross weight of the 1.3 HEF (30 per cent more heat content than JP fuel) airplane as 210,000 lbs. for a cruise speed of 500 knots. The JP fueled airplane for the same range would weigh 288,000 lbs. Conversely, for 288,000 lbs. the 1.3 HEF airplane will have a range of 4,575 nautical miles at a cruise speed of 500 knots. Still better performance is shown with a 1.5 HEF (50 per cent more heat content than JP fuel).

Although HEF provides significant improvements at cruising speeds of 500 knots, the improvements are much more significant at supersonic speeds. It will be noted that a 500,000-lb., 1.3 HEF airplane would provide a range of 1,750 nautical miles at 1,000 knots cruising speed, Fig. 5(c). With the assumptions made in this analysis, 1,750 miles range cannot be achieved at any weight with a JP fueled transport of 1,000 knot cruise speed.

An improvement in the gross weight versus range values in going from 750 knot to 1,000 knot cruising speed is apparent; compare Figs. 5(b) and 5(c). The inversion is due to the relatively small decrease of L/D from 750 knots to 1,000 knots. At the same time, the overall efficiency of the jet engine improves at a higher rate in going from 750 knots to 1,000 knots.

The question immediately arises as to whether an even higher cruise speed would show a still greater improvement. The answer is in the affirmative and can be seen in Figs. 6(a) and (b). Note that when cruising at 1,725 knots less take-off weight is required for a given range than when cruising at 1,000 knots. The fact that the absolute value of the L/D for Fig. 6 is higher than for Fig. 5 does not modify this conclusion. The same trend will prevail at lower absolute values of L/D so long as the differences in L/D values between the two speeds are proportional. No attempt was made to determine a practical optimum supersonic cruise speed.

In Fig. 6(a), the improvements in gross weight with improved aerodynamic efficiency can be seen by comparing the 1,000 knot cruise speed values with those of Fig. 5(c). Whereas it was impossible to design a JP fueled airplane to cruise at 1,000 knots for a distance of 1,750 nautical miles with normal values of L/D, it becomes quite attractive at a gross weight of 250,000 lbs. if a 50 per cent improvement in L/D can be achieved. At a cruise speed of 1,725 knots, an even greater improvement is indicated. With 1.3 HEF, a cruise speed of 1,725 knots, and improved values of L/D, the gross weight becomes quite manageable, indeed, for even much greater stage distances. For a nonstop flight between New York and Paris at 1,725 knots, allowing a range of 3,500 nautical miles the gross weight is shown to be 380,000 lbs. for the 1.3 HEF and only 300,000 lbs. for the 1.5 HEF. It should be evident from Fig. 6 that the benefits from HEF are superimposed on any other improvements.

The values in Figs. 5 and 6 are all based on the same payload of 144 passengers and their requirements. Considerable improvement in range of the supersonic airplanes is possible by replacing passengers with fuel. For example, Fig. 5(c) shows that the ranges for a 400,000-lb. airplane are 1,130, 1,520, and 1,750 nautical miles for the JP, 1.3 HEF, and 1.5 HEF, respectively. Under exactly the same conditions but reducing the numbers of passengers to 72 and replacing their weight

FIGURE 4
LIFT TO DRAG RATIO VS SPEED

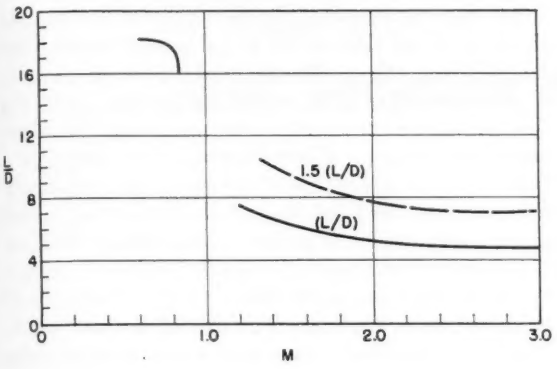


FIGURE 5
RANGE VS GROSS WEIGHT

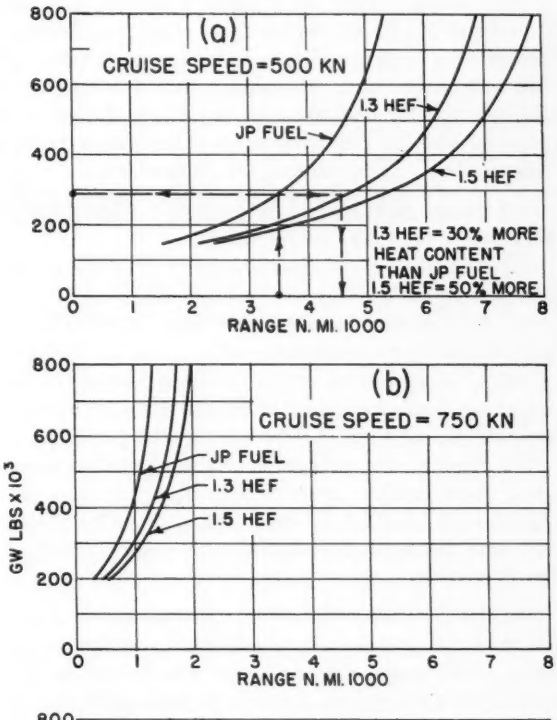


FIGURE 6
RANGE VS GROSS WEIGHT
L/D VALUES INCREASED BY FACTOR OF 1.5

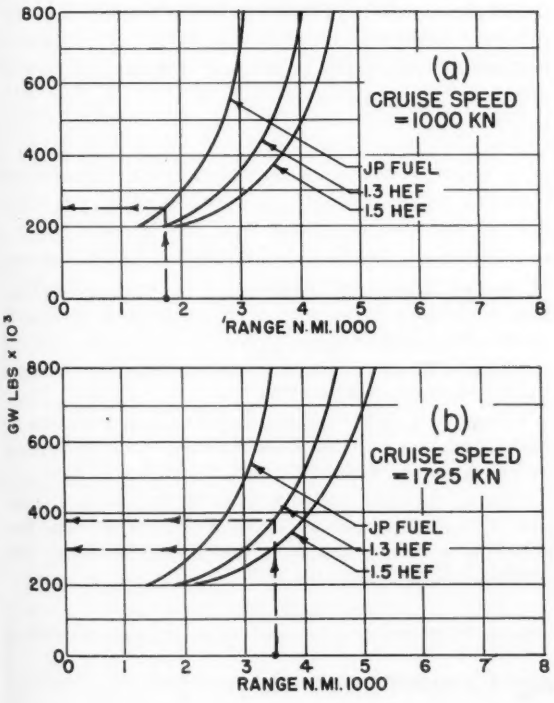
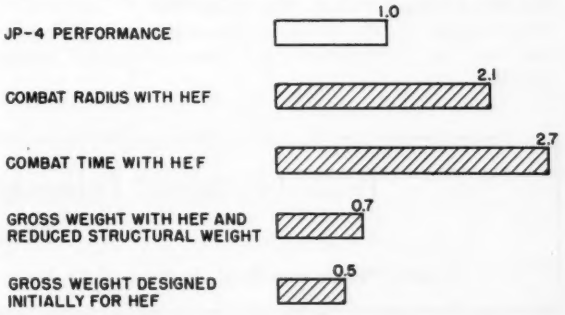


FIGURE 7
PERFORMANCE COMPARISON OF A FIGHTER AIRCRAFT



and furnishings only with fuel the respective ranges increase to 1,470, 1,970, and 2,250 nautical miles.

Effects on a Military Aircraft

The effects of HEF on a military aircraft were also investigated. As a basis for comparison, a preliminary design of a typical military fighter aircraft using JP fuel was carried out. Its performance was computed. Following that, a number of varying conditions were imposed and the performance or other characteristics redetermined. The varying conditions were:

(1) Substituting an equal weight of 1.5 HEF for JP fuel, determine the resulting radius.

(2) Substituting an equal weight of 1.5 HEF for JP fuel, determine the increased combat time.

(3) Substituting just enough weight of 1.5 HEF to perform the same mission as when using JP fuel and allowing the structural weight to change, determine the reduction in gross weight (the engine size was the same as in conditions 1 and 2 above).

(4) Allowing the various factors to change as necessary, determine the gross weight of an airplane, designed with 1.5 HEF, to carry the same military load and have the same performance and mission profile as the JP airplane.

Results are shown in Fig. 7. The first bar in Fig. 7 has the value of unity. It represents the JP fuel design which is the base for comparison. The bar below that shows that the radius can be increased to approximately two times the basic radius by substituting an equal weight of 1.5 HEF for JP fuel. Similarly, the combat time can be increased by a factor of about 2.5. Where the structural weight is also permitted to vary, condition 3, the weight reduction is significant as shown by the fourth bar. Performance parameters such as high speed, rate of climb, maximum ceiling, acceleration, and maneuverability would also be much improved in this case since the engine is larger than needed to meet the basic performance. The last bar shows the marked reduction in gross weight that is possible if the design is completely tailored to the use of 1.5 HEF.

The increase in combat radius in Fig. 7 is considerably in excess of the ratio of B.t.u. per pound between the 1.5 HEF and JP. An explanation for the difference is readily available. The cruise fuel weight itself will provide 50 per cent more radius just from the added energy per pound. When computing the radius of a fighter, certain allowances of fuel are made for take-off, combat, loiter, and reserve. None of this fuel is used in the computation of radius. Substituting HEF for JP allows an increment of weight to be saved in each one of the portions of the mission which does not add to the distance that may be counted toward radius. The sum of the increments saved, when added to cruise fuel weight, provides the added increment of radius over that ascribed to increase of B.t.u. per pound only.

Conclusion

High-energy fuels offer the possibility of very significant improvements in the performance of both commercial and military aircraft. The combination of high-energy fuels and marked improvements in aerodynamic efficiency offer the possibility of supersonic commercial transports at take-off weights comparable to present jet transport designs.

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In outer space travel conventional methods of navigating are not expected to be sufficiently accurate; the use of thermal detectors may solve the problem.

An Application of Solar Radiation to Space Navigation

S. James Press
Douglas Aircraft Company, Inc.

BECAUSE TRAVEL through outer space inherently involves inordinately high flight times and distances, it is improbable that the conventional methods of navigating, wherein the error buildups are time and distance dependent, will be sufficiently accurate. Since the direction of a space vehicle from the origin of a given coordinate system can be found by conventional star or planetary fixing techniques, the major problem in position determination in space becomes one of range or distance determination. This study examines the feasibility of determining range in space by means of a passive thermal radiation sensing system. The coordinate system to be employed is solarcentric. Distance from the sun at any instant is measured by analyzing the radiant power impinging on the sensitive elements of a thermal detector sensitive to a slight change in temperature for its response; thermocouples, thermopiles, and bolometers are all in this category.

The flux density, F, of radiation from a surface of area A at a distance D from a radiating body is the radiant energy per second passing through a unit area, which is normal to the line-of-sight to the emitting surface.[1]

$$F = (\epsilon\sigma A T^4)/(\pi D^2) \qquad (1)$$

where

ϵ = total emissivity of the surface
σ = Stephan-Boltzmann constant
T = absolute temperature of the radiating body
A = surface area of the radiating body
D = distance from the radiator to the detector

In order for Eq. (1) to be useful, D is required to be at least ten times greater than the lateral dimensions of the radiating body. Otherwise, it is necessary to modify the relation in accordance with Lambert's cosine law[2] and integrate the radiation over the entire solid angle subtended at the detector by the radiator.

Since the temperature change and response of a thermal receiver exposed to a radiation flux from a distant body will depend not only on the flux density received but also on the energy radiated from the detector, it is necessary to determine the net exchange of radiant energy between the object and the detector. This subject is discussed in greater detail later. Let the radiating body be the sun, and let the detector be located in a vehicle within the solar system but sufficiently distant from any planet as to be unaffected by atmospheric effects.

The radiant power, P_S, received by the detector of area A_D is given by

$$P_S = A_D F_S = (\epsilon_S \sigma T_S^4 A_S A_D)/(\pi D^2) \qquad (2)$$

where the subscript S refers to the sun.

In like fashion, the radiant power transmitted to the sun by the detector is

$$P_D = A_S F_D \qquad (3)$$

where F_D is the flux density from the detector received at the sun. Thus

$$F_D = (\epsilon_D \sigma T_D^4 A_D)/(\pi D^2) \qquad (4)$$

where ϵ_D = total emissivity of the detector surface, and T_D = absolute temperature of the detector surface. Then

$$P_D = (\epsilon_D \sigma T_D^4 A_D A_S)/(\pi D^2) \qquad (5)$$

If it is assumed that most of the energy radiated from the detector can be directed back toward the sun, the net exchange of power is given by

$$\Delta P = P_S - P_D = [(\epsilon_S \sigma T_S^4 A_S A_D)/(\pi D^2)] - [(\epsilon_D \sigma T_D^4 A_D A_S)/(\pi D^2)]$$

or
$$\Delta P = [(\sigma A_S A_D)/(\pi D^2)]\,(\epsilon_S T_S^4 - \epsilon_D T_D^4) \qquad (6)$$

Since the sun can be considered to be a perfect

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radiator[3] at an effective black body temperature of 5,750°K. and the receiver can be made to very closely approximate a black body, let

$$\epsilon_S = \epsilon_D = 1 \tag{7}$$

$$\Delta P = [(\sigma A_S A_D)/(\pi D^2)]\,(T_S^4 - T_D^4) \tag{8}$$

Moreover, since the radiating temperature of the detector is extremely small compared with the solar temperature (especially when raised to the fourth power),

$$\Delta P = (\sigma A_S A_D T_S^4)/(\pi D^2) \tag{9}$$

The cross-sectional area of the sun is

$$A_S = (\pi \rho^2)/4 \tag{10}$$

where ρ is the solar diameter. Now let

$$\rho = \psi\theta \tag{11}$$

where ψ is the astronomical unit or the distance between the earth and the sun; θ is the earth-measured angular diameter of the sun. By substitution,

$$\Delta P = [(\sigma A_D T_S^4)/(\pi D^2)]\,(\pi/4)\psi\theta = (\sigma A_D \psi^2 \theta^2 T_S^4)/(4D^2) \tag{12}$$

Since all quantities in Eq. (12) are either known or can be measured, D can be determined. Let the reference direction in the solarcentric coordinate system be the earth-sun direction. Since the earth-sun distance is a known function of time, the angular position of the vehicle can be found by measuring the angle included between the vehicle-sun and the vehicle-earth. Thus, a complete position determination of the vehicle can be effected in the solarcentric system.

Error Analysis

The significant question which still remains to be answered is one of accuracy. How accurately can the solar distance determination be made? An analysis of the errors involved in the computation is given below.

Taking logarithms in Eq. (12) yields

$$\ln \Delta P = \ln(\sigma/4) + \ln A_D + 2\ln\psi + 2\ln\theta + 4\ln T_S - 2\ln D \tag{13}$$

Taking differentials of Eq. (13),

$$[d(\Delta P)]/\Delta P = [(dA_D)/A_D] + [(2d\psi)/\psi] + [(2d\theta)/\theta] + [(4dT_S)/T_S] - [(2dD)/D] \tag{14}$$

Solving

$$\frac{dD}{D} = \frac{dA_D}{2A_D} + \frac{d\psi}{\psi} + \frac{d\theta}{\theta} + \frac{2dT_S}{T_S} - \frac{d(\Delta P)}{2\Delta P} \tag{15}$$

$$dD = (D/2A_D)dA_D + (D/\psi)d\psi + (D/\theta)d\theta + (2D/T_S)dT_S - [D/(2\Delta P)]d(\Delta P) \tag{16}$$

Now let P_X denote the probable error in the quantity X. Then the probable error in distance, assuming all quantities are uncorrelated,[4] is given by

$$P_D = \sqrt{(D^2/4A_D^2)P_{A_D}^2 + (D^2/\psi^2)P_\psi^2 + (D^2/\theta^2)P_\theta^2 + (4D^2/T_S^2)P_{T_S}^2 + [D^2/4(\Delta P)^2]P_{\Delta P}^2} \tag{17}$$

or

$$P_D = D\sqrt{(P_{A_D}/2A_D)^2 + (P_\psi/\psi)^2 + (P_\theta/\theta)^2 + (2P_{T_S}/T_S)^2 + (P_{\Delta P}/2\Delta P)^2} \tag{18}$$

Substituting for ΔP from Eqs. (9) and (10) yields

$$P_D = D\sqrt{(P_{A_D}/2A_D)^2 + (P_\psi/\psi)^2 + (P_\theta/\theta)^2 + (2P_{T_S}/T_S)^2 + [(2P_{\Delta P})/(\sigma A_D T_S^4)]^2\,(D/\rho)^4} \tag{19}$$

Let

$$K = 2P_{\Delta P}/(\sigma A_D T_S^4) = \text{constant} \tag{20}$$

Then

$$P_D = D\sqrt{(P_{A_D}/2A_D)^2 + (P_\psi/\psi)^2 + (P_\theta/\theta)^2 + (2P_{T_S}/T_S)^2 + K^2(D/\rho)^4} \tag{21}$$

Numerical Evaluation

The precision with which the astronomical unit is known is[5]

$$P_\psi/\psi = 1.138 \times 10^{-4} \tag{22}$$

The minimum detectable power of a thermocouple type of detector[6] is given by

$$P_{\Delta P} = 10^{-9} \text{ watts} \tag{23}$$

for existing conventional detectors. However, since the theoretical limit[5] appears to be about 10^{-10} watts, small improvements are certainly expected.

Since the earth-measured angular diameter of the sun is 31′ 59.3″ of arc,

$$\theta = 1{,}919.3'' \tag{24}$$

Furthermore, by the most accurate methods presently available, the best precision with which an angle can be measured[7] is 5×10^{-3} ″. However, such a measurement (photoelectrically) could be carried out only under the most ideal conditions. For this reason, a more plausible (although still extremely difficult to realize) precision estimate of 5×10^{-2} ″ is used.

$$P_\theta = 5 \times 10^{-2}\,'' \tag{25}$$

Since the responsivity of a thermal detector tends to decrease with increasing cross-sectional area, extremely small apertures of the order of 1.0 mm.^{2} are currently employed. Thus

$$A_D = 1.0 \text{ mm.}^2 = 10^{-2} \text{ cm.}^2 \tag{26}$$

If it is assumed that an uncertainty of 10^{-6} in. exists in the measurement of the linear dimension of the detector

aperture (perhaps 1,000 times better than the manufacturing tolerance achievable),

$$P_{A_D} = 5.08 \times 10^{-7} \text{ cm.}^2 \tag{27}$$

Since the sun has been regarded as a black body radiator with an effective temperature, T_S, of 5,750°K. (obtainable from Stefan's Law),

$$T_S = 5.75 \times 10^3 \text{K.} \tag{28}$$

Making the assumption that this "effective" radiating temperature is measurable only to within about 0.1°K. gives

$$P_{T_S}/T_S = 0.1/(5.75 \times 10^3) = 1.74 \times 10^{-5} \tag{29}$$

Since the Stefan-Boltzmann constant, σ, is given by

$$\sigma = 5.7 \times 10^{-12} \text{ watts/cm.}^2\text{/deg.}^4 \tag{30}$$

the constant, K, defined in Eq. (20) is found to be

$$K = 3.19 \times 10^{-11} \tag{31}$$

Substitution of the numerical values into Eq. (21) gives

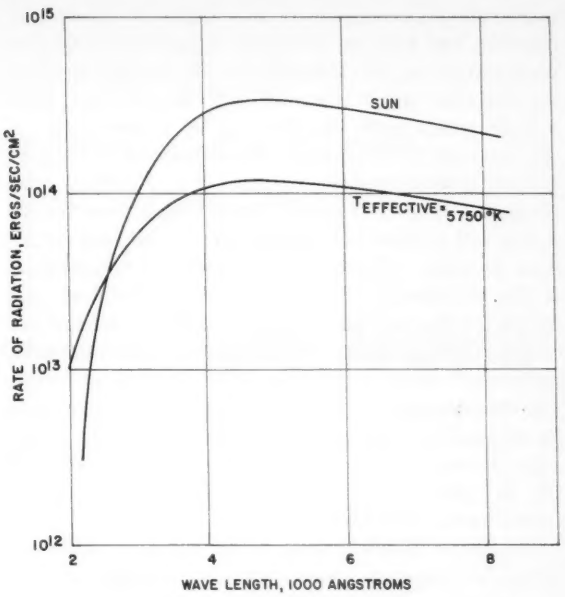

FIG. 2. Solar radiation distribution with wave length.

$$P_D = D$$

$$\sqrt{\left(\frac{5.08 \times 10^{-7}}{2 \times 10^{-2}}\right)^2 + (1.138 \times 10^{-4})^2 + \left(\frac{5 \times 10^{-2}}{1919.3}\right)^2 + (2 \times 1.74 \times 10^{-5})^2 + (3.19 \times 10^{-11})^2 \left(\frac{D}{\rho}\right)^4} \tag{32}$$

or

$$P_D = D\sqrt{1.59 \times 10^{-8} + 10.18 \times 10^{-22} (D/\rho)^4} \tag{33}$$

Since the minimum distance between Mercury and the sun is 28.566 million miles and the maximum distance between Pluto and the sun is 4.3×10^9 miles, the only range under consideration, if the vehicle is to remain within the solar system, is

$$28.566 \times 10^6 \leq D \leq 4.3 \times 10^9 \text{ miles} \tag{34}$$

Moreover, since $\rho = 864{,}392$ miles,

$$33.05 \leq (D/\rho) \leq 4974.59 \tag{35}$$

Since $(D/\rho) \geq 10$, Eq. (1) applies throughout the range of interest and the results which follow are valid.

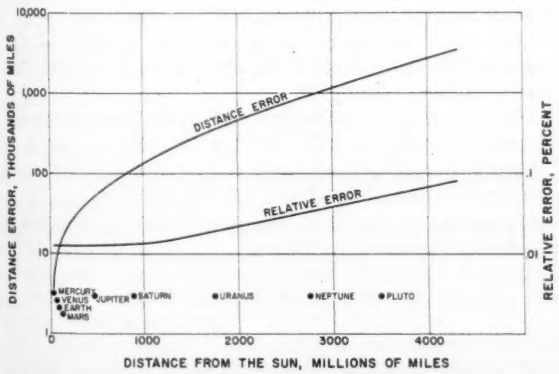

FIG. 1. Position error vs. thermally determined solar distance.

A plot of Eq. (33) is shown in Fig. 1. It may be seen that the error in range to the sun can become as large as 3.46 million miles if the vehicle is at a distance equal to the apogee of Pluto. However, if the space vehicle is traveling in the vicinity of the inner planets, its "heliopath," or distance from the sun determination, will be in error by no more than one earth diameter. The second curve shows that the relative heliopath error will vary between 0.01 and 0.1 per cent.

Although the absolute errors in position appear to be large by comparison with errors existing in earth navigation systems, the relative errors are actually comparable with those presently attainable in the best inertial navigation systems. Furthermore, since navigation in space requires only navigating to the vicinity of massive bodies, the errors quoted above should certainly be acceptable, especially in light of the fact that the thermal measuring system investigated above would probably be extremely lightweight, small, and completely passive. Since the space vehicle would transfer to a local planetary coordinate system when in the near vicinity of a body, the heliocentric system would have to be used only for interplanetary operations.

So far, little has been said of the manner in which the solar radiation is to be measured. It was pointed out early in the discussion that the thermal detector re-

quired should be responsive to a slight change in temperature and that the detector output should be proportional to the net exchange of radiant power between the radiating object (the sun) and the detector. Such a technique is made possible only by proper design of the detector. For example, if the detector is designed so that its sensitive area is located in a cylindrical tube, the radiation to the exterior of the vehicle from the detector will be directed mostly back to the sun rather than to space. Furthermore, if the wall temperature of the cylindrical tube is thermostatically controlled to the temperature of the detector, the isothermal enclosure so obtained does not permit any net power to be exchanged between the tube walls and the detector. The thermostatic control of the wall temperature could be effected by comparison circuitry through the resistance temperature of the sensor. In such a system, Eq. (6) provides the expression for the detector response as a function of heliopath.

The major disadvantages of the thermal measuring system are twofold. First, the path between the vehicle and the sun must not be occluded by any heavenly bodies. This condition should not be too difficult to satisfy since all the planetary orbit planes lie close to the ecliptic and the probability of a solar eclipse is small. The second problem centers about variations in the flux density of radiation from the sun.[8] During periodic surges of solar storms, it is possible for the effective solar radiating temperature and the flux density to fluctuate somewhat. A comparison of the radiation rate of the sun is made with the "effective" radiation curve[3] in Fig. 2. Although Fig. 2 shows that in the visible and infrared region of the spectrum the sun can be treated as a black body, during periods of great solar activity variations may occur.

Another area requiring consideration is the one of solar tracking. Whether position determinations are to be made continuously or periodically, it will be necessary for the thermal radiation sensor to be located in a direct line of sight to the sun. If position determinations are required continuously, the sensor orientation must be electromechanically slaved to the sun. If the position determinations are required only periodically, some means of sun location, such as telescopic finding equipment, must be employed. In either case, a thermal window and a gimballed thermal sensor are probably required.

The question naturally arises as to whether or not it is possible to obtain position in space much more accurately by some other technique, such as star observation.

Observation of the stars from a vehicle very distant from the earth is not sufficient to obtain positional information since the stars are so far away that, for all practical purposes, they are points at infinity, and, therefore, only angles can be measured. The only information that can be gathered from star observations in space is the direction of the radius vector from the origin of the coordinate system to the vehicle. To determine absolute position, the magnitude of the radial vector must be known. If an attempt is made to measure the radial vector by measuring the apparent solar diameter, as has been suggested elsewhere,[9] the resulting error in range would be about 100,000 miles at a range of about one astronomical unit. This error is one order of magnitude greater than the error which would be obtained in a thermal system.

It should also be noted that position determination accuracies can be improved considerably by performing observations on the planets instead of the stars. However, it would then be necessary to carry an extremely accurate time base, such as an atomichron, aboard the vehicle, in addition to having vast quantities of stored data involving planetary positions as a function of time. Analogous data are needed for star observations also, however, to a lesser extent. Although the position variation of the destination with time is also required in the thermal measuring system, the quantity of information necessary is small.

In summary, it appears that a system of space position determination with respect to the sun, by means of thermal detectors, might be a useful solution to the problem of navigating in space. There is still much work to be done in determining the constancy of the parameters involved. For example, measurements of solar radiation and its fluctuations in space can be carried out today by instrumented satellites. After such tests are carried out, the thermal position system could become a reality.

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XUM

The concept of equivalence is introduced as the identity of flutter eigenvalues derived from equations of differing configurations; this concept serves to appraise qualitative flutter behavior in design and remedial studies.

Equivalent Configurations in Flutter Analysis

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SYMBOLS

(See also Fig. 1)

- ab = distance aft of midchord of nodal line in torsion
- b = local wing semichord
- eb = distance (aft of the midchord) of the flap hinge line
- k, k_r = reduced frequency; $\omega b/V$, $\omega b_r/V$, respectively
- k_j = modal reduced frequency; $\omega_j b_r/V$
- k_k = factor multiplying kth column of flutter determinant
- k_o = a particular one of the k_j
- m = mass per unit span
- q = generalized coordinate
- s = wing span, centerline to tip
- x = streamwise coordinate axis, positive aft of reference axis
- y = spanwise coordinate axis, with origin at centerline
- z = vertical displacement, positive downwards
- A = twist of flap relative to main surface at inboard end
- B = twist of flap relative to main surface at outboard end
- G = factor multiplying direct flutter coefficients ($j = k$)
- I = second mass moment per unit span, about spanwise reference axis (subscript α) or about hinge line (subscript β)
- K = factor multiplying a row
- K_1, K_2 = parametric factors for aileron span and position, respectively
- L = complex lift per unit span, at leading edge
- M = complex moment per unit span on wing surface
- S = first mass moment per unit span
- T = complex aileron hinge moment per unit span
- V = forward true air speed
- α = chordwise slope, positive nose up, of wing; see Eq. (13)
- β = chordwise slope, positive nose up, of flap; see Eq. (13)
- η = spanwise coordinate, y/s
- η_1 = station η of flap inboard end
- η_2 = station η of flap outboard end
- ξ = chordwise coordinate, $x/2b_r$
- $2\xi b$ = distance (aft of leading edge) of nodal line, torsional mode; $\xi = (1/2)(1 + a)$
- ρ = free-stream air density
- ω = circular frequency
- Γ = factor multiplying coupling flutter coefficients ($j \neq k$)

Subscripts

- α = wing properties, measured about leading edge, due to incidence
- β = flap properties, measured about hinge line
- h = wing properties, measured at leading edge, due to vertical translation
- j = for the jth mode or row
- k = for the kth mode or column
- jk = for coupling between the jth and kth modes
- r = for the reference semichord (wing tip)

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OPTIMUM structural configurations of airplanes are today more and more influenced by aeroelastic and, in particular, flutter considerations, and the practicing aeroelastician may be called upon to exercise his talents along these lines, either in design preventive studies or, if success is not immediate, in remedial investigations. In either case, he is concerned with the general behavior of the fluttering system when subject to a wide variation of structural, geometrical, dynamic, and aerodynamic parameters. He has at his disposal to assist him in this estimate (short of elaborate and costly detailed calculations) such approximate guides as design criteria, statistical surveys, wind-tunnel model results, and his experience. All such aids have as a common factor, either consciously or intuitively, the principles of similarity. One additional aid, proposed here—that of configurational equivalence—demands only partial similarity and is offered in the belief that it represents a powerful means of obtaining qualitative or quantitative estimates of flutter behavior of configurations derived from a standard system whose characteristics are fully known. The concept of equivalence is a simple one and has been used with

success by the author[1] in a not generally available publication. It is here reported in rather more generality and detail, and illustrated by reference to the binary flutter of a simplified three-dimensional wing-aileron system. In this example it is possible, through the equivalence concept, to demonstrate the stabilizing influence of the variation of such parameters as aileron span and position, wing nodal lines of symmetric and antisymmetric modes, aileron twisting modes, and of the spanwise position of control actuation. This by no means exhausts the possibilities of useful application to the estimate of flutter behavior of myriad other configurations based on the flutter calculations of a *single* configuration.

Equations of Motion

Consider first a fluttering system of n degrees of freedom described in terms of the nondimensional generalized coordinates q_j, $j = 1, 2, \ldots n$. The equations of motion are expressible in nondimensional form as the matrix equation

$$[\delta_{jk}] \{q_j\} = 0 \tag{1}$$

where the elements δ_{jk} of the $n \times n$ square matrix are written, by a simple generalization of the standard binary equations,[2] as

$$\begin{aligned} \delta_{jk} &= A_{jk} + iB_{jk} \\ &= a_{jk} \{1 - (1 + ig_j)\psi_j\Omega\} + Q_{jk} \end{aligned} \tag{2}$$

Here the flutter coefficients a are the generalized inertias, g are the modal structural damping coefficients, and Q are the generalized (aerodynamic) forces. Only the latter are functions of the reduced frequency k_r which appears in the ratio $\Omega = (k_o/k_r)^2$. The particular modal reduced frequency k_o defines the ratio $\psi_j = (k_j/k_o)^2$ where k_j is the reduced frequency of the jth mode. Only when $j = k$ are g, Ω, ψ considered meaningful and nonzero. The form (2) implies, then, complete absence of structural coupling which restricts the choice of the q_j to normal modes, for example.

Determinantal Flutter Equation

The conditions (Ω, g) pertaining to a critical flutter state follow immediately as the condition for nontrivial roots q_j of Eq. (1). Thus

$$|\delta_{jk}| = 0 \tag{3}$$

which upon expansion yields the characteristic polynomial stability equation.

Equivalent Configurations

Let K_j, k_k be real constant, nonzero multiplying factors applied to the determinant $|\delta_{jk}|$ so that K_j multiplies its jth row and k_k its kth column. The derived determinant is, by an elementary rule of determinants,

$$\begin{aligned} |K_jk_k\delta_{jk}| &= \prod_{j=1}^{n} K_j \prod_{j=1}^{n} k_j \, |\delta_{jk}| \\ &= 0 \end{aligned} \tag{4}$$

by Eq. (3). The left-hand side of Eq. (4) pertains to the new equations of motion

$$[K_jk_k\delta_{jk}] \{q_j/k_j\} = 0 \tag{5}$$

where the q_j are the solutions of Eq. (1). We define as equivalent configurations the two systems represented by the two determinants in Eqs. (3) and (4), whose respective equations of motion are given by Eqs. (1) and (5). They are *equivalent* in the sense that the same flutter eigenvalues satisfy each of their characteristic equations.* Complete similarity is not attained, however, because of the differing modal columns. This is here an irrelevant restriction. In application, the two systems have identical flutter frequencies and air speeds while the defect of modal amplitude disparity can, from the viewpoint of design stability, be accepted because prime interest is centered on the critical speed.

Existence of Equivalence

We should inquire now as to whether the determinant of Eq. (4) does, in fact, correspond to a real physical system derivable from the initial system through the use of the factors K_j, k_k.

Let s_i, $i = 1, 2, \ldots w$ be the total number of system parameters so that $\delta_{jk} = \delta_{jk}(s_i)$. Apply to each parameter s_i the real parametric factor t_i and ascribe to the resultant effective factor on δ_{jk} due to the single t_i the symbol $(C_{jk})_i$. Then the overall resulting factor T_{jk} on δ_{jk} is

$$T_{jk} = \prod_{i=1}^{w} (C_{jk})_i \tag{6}$$

and we observe that

$$T_{jk}\delta_{jk}(s_i) = \delta_{jk}(t_is_i), \quad i = 1, 2, \ldots w \tag{7}$$

so that Eq. (7) defines a physically derived new system. It is equivalent to its parent, specified by $\delta_{jk}(s_i)$, according to Eq. (5) if the n^2 factors T_{jk} are such that the $2n$ factors K_j and k_j satisfy

$$K_jk_k = T_{jk} = \prod_{i=1}^{w} (C_{jk})_i \tag{8}$$

which is the restricting condition on the existence of equivalence.

In order to illustrate in a specific way what this means, consider the system $n = 2$ in which

$$\begin{vmatrix} \delta_{11} & \delta_{12} \\ \delta_{21} & \delta_{22} \end{vmatrix} = 0$$

and suppose any number of parametric changes are made so that each element δ_{jk} of the stability determinant is effectively multiplied by a factor T_{jk}. For equivalence to exist, these factors must be interpretable as products of row and column multipliers; thus

$$\left.\begin{aligned} T_{11} &= K_1k_1, \quad T_{12} = K_1k_2 \\ T_{21} &= K_2k_1, \quad T_{22} = K_2k_2 \end{aligned}\right\} \tag{8a}$$

* This concept is, as far as Eq. (5) is concerned, completely identical to the scaling procedures used in analog computing techniques to optimize numerical values of flutter coefficients.

which is a system of $4(=n^2)$ nonlinear nonhomogeneous equations relating $4(=2n)$ unknowns K_j, k_j. By appropriate elimination it is not difficult to show that these equations imply

$$(T_{11}T_{22} - T_{12}T_{21})^2 = 0 \tag{8b}$$

This relation must be satisfied so that a solution can exist. It is also clear in this case that, of the four quantities K_j, k_j, one is arbitrarily disposable.

To fix ideas more concretely, suppose that the four δ_{jk} are all functions of two parameters s_1, s_2 in such a way that $T_{jk} = f_{jk}(s_1, s_2)$; then, from Eq. (8b) all systems are equivalent which satisfy the condition

$$f_{11}(s_1, s_2)f_{22}(s_1, s_2) - f_{12}(s_1, s_2)f_{21}(s_1, s_2) = 0 \tag{8c}$$

which is simply a functional relation between s_1 and s_2. An important particular case is given by $f_{11}(s_1, s_2) = 1$, and $f_{12}(s_1, s_2) = f_{21}(s_1, s_2)$ when

$$f_{22}(s_1, s_2) - [f_{12}(s_1, s_2)]^2 = 0 \tag{8d}$$

A Special Equivalent Configuration

It is perhaps of little added value to generalize further, beyond noting that condition (8) cannot usually be met in all generality. Each system is best studied individually in terms of the analytic expressions for its flutter coefficients. It is frequently desirable in practice, however, to consider systems equivalent with respect to at most two system parameters, when $w = 2$, as just discussed for a binary system. In addition, it is not uncommon (in control surface flutter, for example) for these parameters to be restricted in Eq. (3) to a single pair of row and column, say the last, for which $K_j = K_n$, $k_k = k_n$. Then, without restriction on w, for all elements δ_{jk} for which $j, k \neq n$

$$T_{jk} = K_jk_k = 1 \tag{9}$$

satisfies condition (8); while for the nth row and column

$$T_{nk} = K_n, \quad T_{jn} = k_n, \quad T_{nn} = K_nk_n \tag{10}$$

If, in particular, $T_{nk} = T_{jn}$, $j \neq k$, then $K_n = k_n = \kappa$, $K_nk_n = \kappa^2$ which requires that the overall factors applied to *all* the coupling terms appropriate to the nth degree of freedom because of parametric variations be equal to the square root of the factor applied to the direct terms. This simple condition is analogous to that of Eq. (8d) above and is used in the sequel as an illustration of the useful and comprehensive results which can be extracted from the equivalence concept. Attention is directed to the wing-aileron flutter problem in which the further simplification $n = 2$ is made so that the primary binary couplings of this type of flutter are considered.

Wing-Aileron Flutter

In order to apply the equivalence condition, it is necessary to establish general expressions for the nondimensional flutter coefficients a, Q of Eq. (2). A simple example which demonstrates with some realism the efficacy of the method is afforded by a spanwise uniform, rectangular wing carrying a flap of uniform spanwise properties. The generalized inertias a_{jk} and the corresponding generalized aerodynamic forces Q_{jk} are given in this case by

$$\left.\begin{aligned} a_{jk} &= (1/2\rho b^4)[4mb^2\zeta_j\zeta_k - 2S_\alpha b(\zeta_j + \zeta_k) + I_\alpha] \int_o^1 F_jF_k\,d\eta \\ a_{j\beta} &= (1/2\rho b^4)[bS_\beta(1 + e - 2\zeta_j) + I_\beta] \int_{\eta_1}^{\eta_2} F_jF_\beta\,d\eta \\ a_{\beta\beta} &= (1/2\rho b^4)[I_\beta] \int_{\eta_1}^{\eta_2} F_\beta^2\,d\eta \end{aligned}\right\} \tag{11}$$

and

$$\left.\begin{aligned} Q_{jk} &= (\pi/8)[4\zeta_j\zeta_kL_h + 2(\zeta_j + \zeta_k)(M_h - L_\alpha) - M_\alpha] \int_o^1 F_jF_k\,d\eta \\ Q_{j\beta} &= (\pi/8)[-2\zeta_jL_\beta - M_\beta] \int_{\eta_1}^{\eta_2} F_jF_\beta\,d\eta \\ Q_{\beta j} &= (\pi/8)[2\zeta_jT_h - T_\alpha] \int_{\eta_1}^{\eta_2} F_jF_\beta\,d\eta \\ Q_{\beta\beta} &= (\pi/8)[-T_\beta] \int_{\eta_1}^{\eta_2} F_\beta^2\,d\eta \end{aligned}\right\} \tag{12}$$

in which the mass, moment, and inertia properties of the wing and the air force coefficients have their usual symbols. The symbols f_j, F_j, F_β define nondimensional modal weighting functions for the jth wing mode and the aileron (β), and are related to the wing and aileron displacements by

$$\left.\begin{aligned} z_j(y)e^{i\omega t} &= 2bf_j(y)q_je^{i\omega t} \\ \alpha_j(y)e^{i\omega t} &= F_j(y)q_je^{i\omega t}, \quad j = 1, 2, \ldots n \\ \beta(y)e^{i\omega t} &= \\ & F_\beta(y)q_\beta e^{i\omega t}, \quad \eta_1 \leqslant \eta \leqslant \eta_2, \quad (1/2)(1 + e) \leqslant \xi \leqslant 1 \end{aligned}\right\} \tag{13}$$

The wing nodal line position is defined by the parameter ζ_j thus

$$\zeta_j = -f_j/F_j = (1 + a_j)/2 \tag{14}$$

Expressions (13) and (14) imply no chordwise distortion and straight nodal lines. The flutter coefficients Q arising from the generalized forces are given on the basis of strip theory for simplicity, and beyond this assumption the actual form of the air forces, apart from the appearance of the functions f_j, F_j, is of no significance here.

We observe from expressions (11) and (12) that for any binary coupling, which includes the aileron mode F_β, the modal integrals appear significantly as factors in all flutter coefficients. Thus, for example, a_{jj} and Q_{jj} both contain as multiplier the integral $\int_o^1 F_j^2 d\eta$; $a_{\beta j}$, $a_{j\beta}$, $Q_{\beta j}$, $Q_{j\beta}$ all contain as multiplier the integral $\int_{\eta_1}^{\eta_2} F_jF_\beta d\eta$; $a_{\beta\beta}$ and $Q_{\beta\beta}$ both contain as multiplier the integral $\int_{\eta_1}^{\eta_2} F_\beta^2 d\eta$; so that all coefficients $j\beta$ and βj have as factor an integral containing the modal function product F_jF_β, whereas all direct aileron

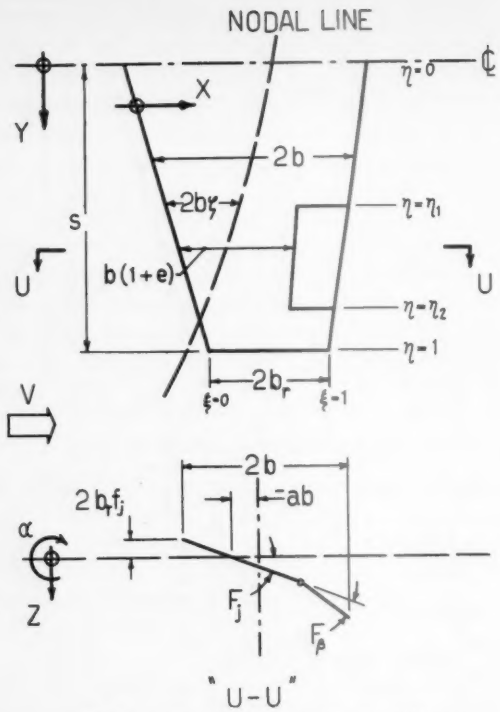

FIG. 1. Coordinate system and notations.

coefficients contain as factor an integral containing F_β^2. The system is ripe for equivalence; since any factor applied to the first integral as a result of a change in *any* of the parameters occurring therein need be related* to the factor G on the second integral because of the same changes only by the simple equality

$$G = \Gamma^2 \tag{15}$$

A similar result obtains when the integrals containing F_j^2 and F_jF_β are considered as a pair, and, in this case, application of the equivalence condition leads to information bearing more on the wing than the aileron.

In order to exploit Eq. (15) in such a way as to both retain some reality and at the same time demonstrate readily the potency of the results accruing, some simple pure modes are chosen in analytic form. Both "flexural" and "torsional" modes for symmetric and antisymmetric oscillation are considered.

WING FLEXURE: AILERON FLUTTER

In this case the displacements of the binary system are described, from Eq. (13), only in terms of f and F_β because now $\alpha = F = 0$ is required to restrict the wing motion to one of pure flexure. Consider, for example, the symmetric mode

$$f(\eta) = (\eta^2 - \eta_3^2)/(1 - \eta_3^2), \quad F(\eta) = 0 \tag{16}$$

where η_3 is the distance from the wing centerline of the chordwise flexural nodal line, together with the aileron linear twisting mode

$$F_\beta(\eta) = [(B - A)\eta + A\eta_2 - B\eta_1]/(\eta_2 - \eta_1) \tag{17}$$

where A, B are parametric nondimensional angles of twist at the aileron end-stations η_1, η_2, respectively. For a nondeforming† flap, $A = B = 1$, and the flap mode is one of relative rotation only. Apart from these modal weighting functions, only the limits η_1 and η_2 of integration enter the Eq. (15). It is of interest to investigate equivalence in terms of these limits which define the inboard and outboard spanwise stations of the aileron. We apply an arbitrary factor K_1 to the aileron span $\eta_2 - \eta_1$ and a second arbitrary factor K_2 to the parameter $\eta_1 + \eta_2$ which determines the aileron spanwise position.

Using the modes (16) and (17) with $A = B = 1$, this process gives rise to the equivalence requirement, from Eq. (10), of

$$K_2^2 = \sqrt{(1/K_1)} + \{\sqrt{(1/K_1)} - K_1^2\}\,\Sigma/3 + \{1 - \sqrt{(1/K_1)}\}\,\Delta \tag{18}$$

where new parameters are defined

$$\Sigma = \{(\eta_2 - \eta_1)/(\eta_2 + \eta_1)\}^2, \qquad \Delta = \{(2\eta_3)/(\eta_2 + \eta_1)\}^2 \tag{19}$$

Any system having its aileron span and position defined in relation to the nodal line position (η_3) of the symmetric bending mode by (19) is then completely identical in flutter frequency and speed to any other system derived from the first by applying the factors K_1, K_2, provided that the relation (18) is valid.

Fig. 2 gives a graphical plot of the equivalence condition (18) for a nondeforming aileron ($A = B = 1$) for a range of values of the parameters Σ and Δ. By

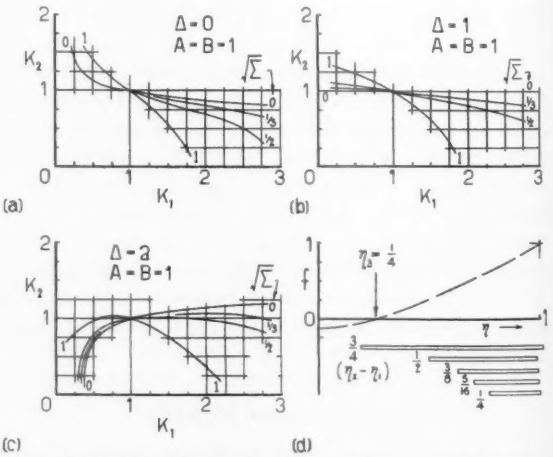

FIG. 2(a), (b), and (c). Solutions for flutter equivalence for symmetric wing bending and nondeforming aileron in terms of wing node, aileron span, and aileron position. (d) Positioning of ailerons of differing span for a prescribed wing mode for bending-aileron flutter equivalence.

* Evidently from Eq. (2) the restriction exists that the modal reduced frequency k_j (and so ω_j) remain unaltered. Any parametric variations made must be compatible with this requirement.

† The flap is nondeforming in the sense that F_β is independent of the spanwise coordinate η. The absolute flap deformation is rotation with sympathetic flap twist in accordance with the variation $F(\eta)$ (see Fig. 1).

way of illustration, these are interpreted in Fig. 2(d) for a quarterspan aileron and a wing having a nodal line at the quarterspan station, $\eta_3 = 1/4$. For such outboard aileron positions the flutter characteristics are evidently little affected by aileron span per se. Fig. 2(b), for example, for which $\Delta = 1$ (the nodal line bisects the aileron), indicates that all other ailerons of whatever span have closely the same position for equivalence. This is certainly not so for outboard nodal lines ($\Delta = 2$), as evidenced by Fig. 2(c).

In a similar manner, the antisymmetric flexural mode

$$f(\eta) = \eta(\eta^2 - \eta_o^2)/(1 - \eta_o^2), \quad F(\eta) = 0 \quad (20)$$

leads to a condition for equivalence in terms of the same factors K_1 and K_2; and where now η_o replaces η_3 in (19)

$$\{\sqrt{(1/K_1)} - K_2{}^3\} + \{\sqrt{(1/K_1)} - K_2K_1{}^2\}\,\Sigma + \{K_2 - \sqrt{(1/K_1)}\}\,\Delta = 0 \quad (21)$$

The relation (21) is graphed in Fig. 3 for $\Sigma = 0, (1/2), 1$, and $\Delta = 0, 1, 2, 4$. Four examples of the application of these figures are given in Fig. 4 in which each set (a), (b), (c), (d) defines equivalent configurations for the given mode. In the case exemplified by $\eta_o = 1/\sqrt{2}$ [Fig. 4(c)], two discrete sets of equivalent systems are shown. It is of interest to note that, once again for extreme outboard positions of the aileron, the flutter behavior is virtually independent of aileron span per se for the values considered. We note also that an antisymmetric wing bending mode offers the possibility of finding two spanwise positions of the same aileron for which equivalence holds. The effects of adding external stores to wings can in this case be estimated because the wing mode is then characterized (for an outboard store, at least) by a nodal line nearer the tip than the root so that Δ becomes comparatively large.

Wing Torsion: Aileron Flutter

The versatility of the equivalence concept is well illustrated by this simple type of binary flutter, and

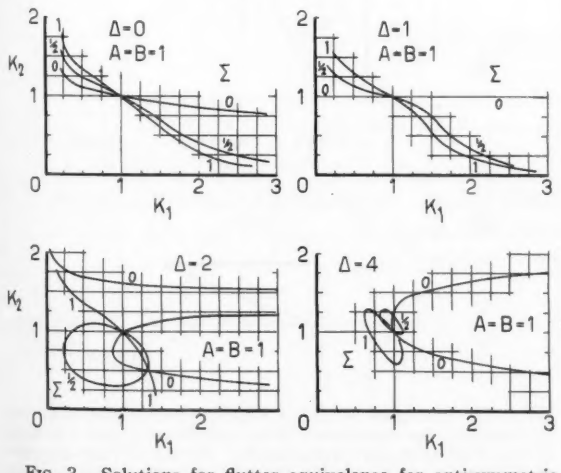

Fig. 3. Solutions for flutter equivalence for antisymmetric wing bending and nondeforming aileron in terms of wing node, aileron span, and aileron position.

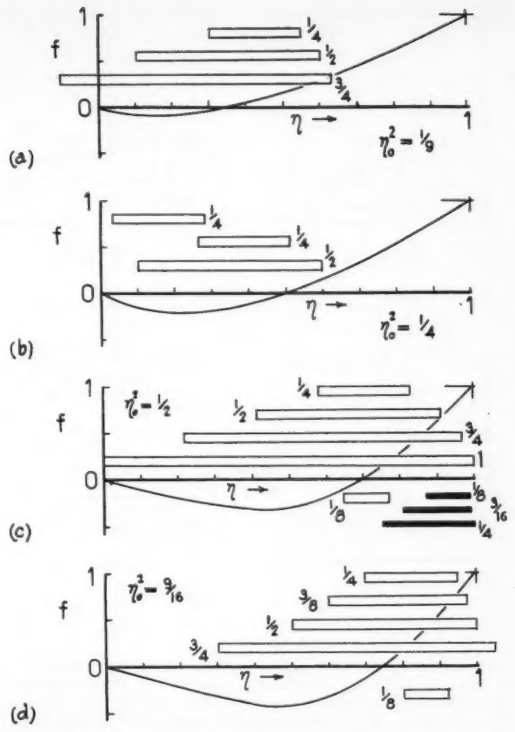

Fig. 4. Antisymmetric wing bending-aileron flutter. Some examples of equivalent configurations for four prescribed wing modes when the aileron is nondeforming.

results are presented which emphasize the role of aileron spanwise twist. As a simple wing mode, the form (22) is convenient

$$F(\eta) = \sin(\eta\pi/2), \quad f = -\zeta F \quad (22)$$

while the aileron mode (17) is again applicable. A general equivalence condition is simply deduced by allowing variations of all three aileron parameters—viz., K_1, K_2, A (or B) where K_1 and K_2 have the same meaning as before. The constants A, B define the end-rotations of the aileron linear twist so that $B - A$ is a measure of the structural distortion of the control surface and $A + B$ is a measure of its rigid body rotation due to deformation of the control actuator system. Thus, in the event that $A = 0$, $F_\beta(\eta_1) = 0$, and $F_\beta(\eta_2) = B$ (which can be normalized to unity), the aileron mode simulates a control surface having irreversible actuation at its inboard end. Similarly, $B = 0$, $A = 1$ represents irreversible actuation at the outboard end.

If then we make only the restriction $B = 1$, the equivalence condition relates two systems characterized, respectively, by the parameters A, $\eta_2 - \eta_1$, $\eta_2 + \eta_1$ for the first, and $A = 1$, $K_1(\eta_2 - \eta_1)$, $K_2(\eta_2 + \eta_1)$ for the second. Equivalence is then satisfied, through Eq. (15), provided

$$\sqrt{3K_1}\,\{(A - 1)\cos E\cdot[\cos D - (1/D)\sin D] + (A + 1)\sin D \sin E\} = 2\sqrt{A^2 + A + 1}\cdot\sin EK_2 \sin DK_1, \quad B = 1 \quad (23)$$

where $D = \pi(\eta_2 - \eta_1)/4$, $E = \pi(\eta_1 + \eta_2)/4$. Several

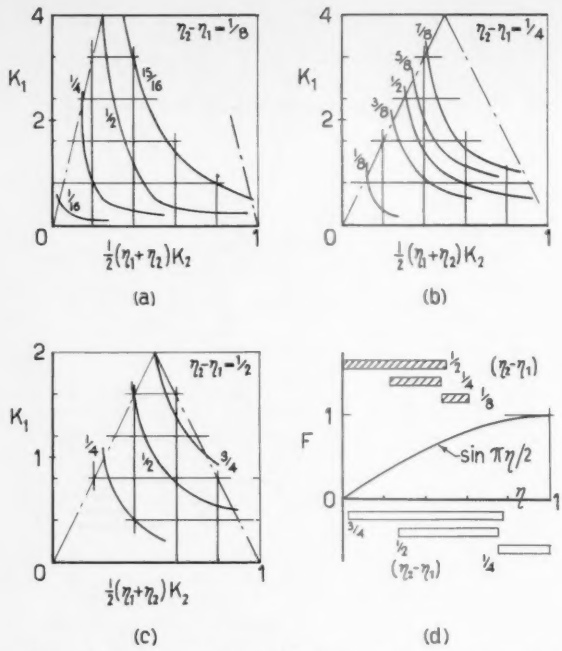

FIG. 5(a), (b), and (c). Solutions for flutter equivalence for wing torsion and nondeforming aileron for three prescribed aileron spans. Numbers against the curves are values of $(1/2)(\eta_2 + \eta_1)$. (d) Positioning of ailerons of differing span for wing torsion-aileron flutter equivalence.

particular cases of this result are of interest and are briefly reviewed here:

(a) $A = 1, B = 1$. The aileron is now nontwisting, and equivalence is between systems of identical aileron mode, differing with respect to aileron span and its position on the wing. A simple solution in this case is found by substituting $K_1 = 2$, $\eta_2 = 1$ in Eq. (23); whence $K_2(1 + \eta_1) = 1$. It follows that a flap of any span placed at its extreme outboard position is always equivalent to a flap of twice the span placed with its midpoint at the midspan (root to tip) wing station. Other solutions for this condition are given graphically in Fig. 5, together with two examples of equivalent systems. To use these graphs, simply select the figure and curve appropriate to prescribed aileron span $(\eta_2 - \eta_1)$ and position $(1/2)(\eta_1 + \eta_2)$; the abscissa then gives the position of an equivalent aileron of span determined by the ordinate K_1. It may be generally concluded that flutter behavior is sensitive to aileron span and position, and that a large span inboard aileron can be made to be flutter stable, whereas a small span outboard aileron of the same control effectiveness may be unstable.

(b) $K_1 = K_2 = 1, B = 1$. The aileron span and position are considered invariant so that the analysis gives a direct indication of the effects of aileron twist. The solution for A for a given pair η_1, η_2 and hence $\eta_2 - \eta_1$, $\eta_1 + \eta_2$ is presented in Fig. 6 together with some samples of equivalent systems having different twisting modes. Thus, an aileron of prescribed span $(\eta_2 - \eta_1)$ and position $(1/2)(\eta_1 + \eta_2)$ defines a point on one of the upper curves corresponding to a value $A = A'$. The two systems having aileron modes $F_\beta(A)$, $A = 1$, and $A = A'$ are equivalent; the first is an untwisted aileron while the latter is twisted, but both are of equal span and position. Fig. 5(c), for example, illustrates the case for $\eta_2 - \eta_1 = 1/2$, $\eta_1 + \eta_2 = 0.90$, whence $A' = 0$. In other words, a nontwisting half-span flap placed with its midpoint at 0.45 of the wing span has the same flutter speed and frequency as a flap with linear twist and inboard irreversible actuation of the same span and position.

(c) $A = 0, B = 1$. The aileron has now irreversible actuation at its inboard end. Fig. 7(a) depicts solutions of Eq. (23) for a variety of aileron spans and positions for the particular aileron mode for which $A = 0$. Three examples of equivalent systems derived from these solutions are given there also. Generally, it may be deduced that, when two equivalent configurations have the same aileron span ($K_1 = 1$), the twisting flap is inboard (or outboard) of the nontwisting flap according to whether the former occupies an inboard (or outboard) position. An interesting corollary relates to the existence of a transitional configuration when the two systems differ *only* in regard to the flap mode.

(d) $A = 1$, $B = 0$. An equivalence condition analogous to Eq. (23) can be set up for $A = 1$ and

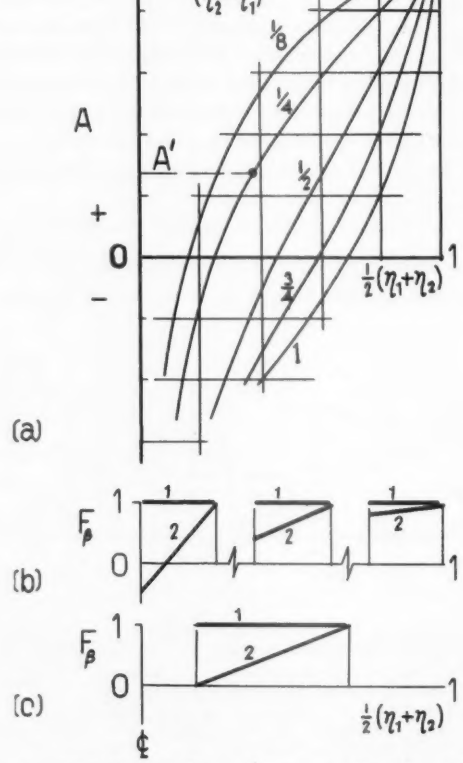

FIG. 6. The effect of aileron twist on torsion-aileron flutter. (a) Solutions for equivalence of a nondeforming and a twisted aileron of the same span and position. (b) and (c) Four examples of equivalence, in which *1* is the aileron trailing-edge displacement of the untwisted surface and *2* is that of the equivalent twisting surface.

arbitrary B by replacing in (23) A by B and $A - 1$ by $1 - B$. Then, with $B = 0$ equivalence refers to an aileron with outboard irreversible actuation. Some derived solutions are given in Fig. 7(b). In this case the untwisted aileron always lies inboard of its equivalent deforming mate. The relevance of this result to flutter prevention will, if not already obvious, become clear upon the realization that for an untwisted aileron a powerfully stabilizing influence results[1] from moving the aileron progressively inboard along the span.

Thus, aileron twist proves to be advantageous for an outboard flap with actuation (irreversible) at its inboard end when considering a torsional mode. It is, however, deleterious when the same aileron is moved far inboard. Provision of irreversible operation at the outboard end of the aileron in conjunction with twist is, on the other hand, strongly stabilizing for all spanwise positions of the control surface, and the effect is the more marked the farther outboard the surface is placed.

Conclusion

It is clear that the equivalence concept has its optimum application in two fields—viz., design studies where comparative estimates of qualitative behavior are required and in remedial studies where it is necessary to discover optimum changes of parameters for a "standard" configuration whose flutter characteristics are quantitatively known. In this latter instance, once the system behavior is fully known in terms of parametric variations of one configuration, so also are known, through the equivalence conditions, the characteristics of a whole host of other configurations.[1]

The extension of the principle of equivalence to variations of other parameters, other modes, and other types of flutter is evident.

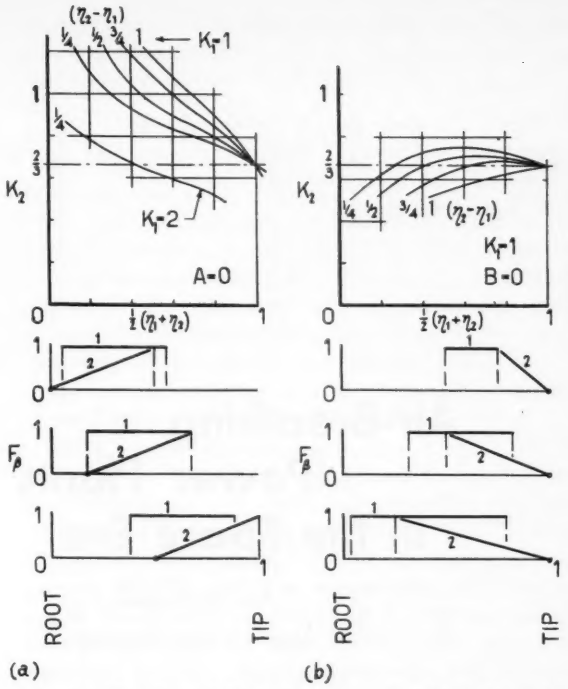

Fig. 7. The effect of aileron twist on torsion-aileron flutter for an aileron with actuation (a) inboard and (b) outboard. Solutions of the equivalence condition together with six examples, showing relative positions on the span and trailing-edge displacement for the rigid surface *1* and the twisting surface *2*.

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[2] Bisplinghoff, R. L., Ashley, H., and Halfman, R. L., *Aeroelasticity*, p. 563; Addison-Wesley Publishing Co., Inc., Cambridge, Mass., 1955.

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"Does it . . . make sense to continue to invest manpower and money in developing air-breathing engines at a time when space flight has become our biggest challenge?"

Air-Breathing Power Plants in the Space Era

Peter G. Kappus

General Electric Company

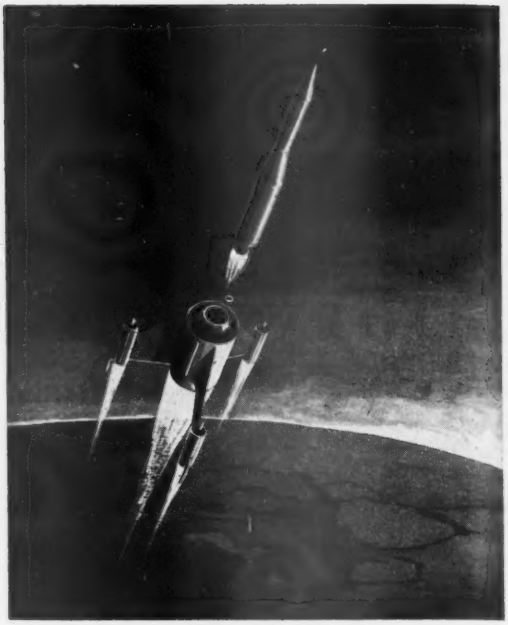

FIG. 5. AIR-BREATHING BOOST

Artist's view of an air-breathing boost vehicle launching a satellite. The recoverable boost unit returns to its base and is fully reusable.

THE RUSSIAN Sputniks have dramatically presented the opening chapter of the Rocket Age. Time has justified the vision of men like Tsiolkofsky, Oberth, and Goddard who fostered and kept alive the dream of rocket-powered space travel. It is only a question of time—perhaps less than we think—and national determination before the first man sets foot upon the moon and the planets.

The rocket engine has been labeled the power plant of the future. If this is true, it is fair to ask, "Has not the rocket engine obsoleted air-breathing engines? Does it, therefore, make sense to continue to invest manpower and money in developing air-breathing engines at a time when space flight has become our biggest challenge?"

In answering these questions, this study will show that the air-breathing power plant has not yet attained its optimum development and has not yet realized its maximum versatility as a power plant for civilian and military use. It will be shown that the air-breathing engine complements the rocket rather than competes with it.

GENERAL GROWTH TRENDS

Turbojets struggled through a frustrating period of growing pains in the late 1930's and finally emerged from World War II as powerful new contenders in the widening spectrum of propulsion devices. The technology of air-breathers is expected to advance for about 10 more years and then enter into a static period of steady production and minor refinements. Most important is the fact that major progress will continue to be made in the direction of low-cost mass production which will lead to extensive use of gas-turbine power by military and private users.

REVIEW OF EXISTING AIR-BREATHERS

The Turbojet

To set the stage, let us quickly review the air-breathing gas-turbine engine types that today have reached operational status. First, there is the straightforward turbojet engine of light weight and high efficiency that has proved so successful in powering a variety of military and commercial aircraft and missiles. The addition of an afterburner has given this engine a boost of additional power which permits speeds higher than twice that of sound.

The Turboprop

The turboprop has unique advantages in cruise efficiency and take-off characteristics which make it an excellent work horse for long- and short-range hauling jobs where speed is of secondary importance.

We shall now take a look into the near future and see what new air-breathing engine types will be developed before this engine reaches full maturity.

Condensed and revised from a paper entitled "The Future of Air-Breathing Power Plants" presented before the IAS Niagara Frontier Section, Buffalo, N.Y., May 14, 1958.

Mr. Kappus is Manager, New Product Planning, Flight Propulsion Laboratory Department, Aircraft Gas Turbine Division.

The Turbofan—the Ideal Logistics Engine at Subsonic Speeds

To Rolls-Royce goes the credit for having brought the first turbofan-type engine to operational maturity. Manufacturers in the United States are currently introducing turbofans of excellent performance. The turbofan requires extremely high component efficiencies and is more complex to develop than the turbojet. Until recently the turbofan took a back seat to the turbojet, but the day is not far off when the turbofan will largely replace the turbojet as the ideal logistics engine at subsonic speeds, for the following reasons: greater propulsive efficiency, higher take-off thrust, and lower noise level.

The real limitation of the turbojet is determined by its propulsive efficiency, which is a function of the ratio of jet velocity to flight speed. Any increase in internal efficiency of the engine will lead to higher jet velocity since this is the only output of the turbojet. These higher jet velocities lower the engine's propulsive efficiency. Here is the paradox of the turbojet—as components are improved higher jet velocities are attained, but part of the gain in component efficiency is lost again through lower propulsive efficiency.

The paradox of the turbojet is answered by the turbofan. Propulsive efficiency is not reduced as internal components are improved because jet velocities can be kept constant. The by-pass ratio can be increased by passing more air through the fan, resulting in constant propulsive efficiency. The result is a gain in thrust and specific fuel consumption in direct proportion to component improvements.

Another highly desirable factor is the higher take-off thrust of the turbofan which offers outstanding advantages over the turbojet. In existing aircraft, higher take-off thrust will markedly improve take-off runs, permitting shorter runways. In aircraft designed for the turbofan, the new engine will permit higher wing loadings, thus making possible greater payloads and increased operating economy.

The advantages of reducing jet noise are self-evident.

Combining the advantages of both its parents—the simple fast turbojet and the economic turboprop—the turbofan promises to be the ideal engine for subsonic transports and logistics carriers.

The VTOL Engine

The vertical take-off and landing engine is an intriguing newcomer in our air-breathing engine family. The VTOL engine is ideal for dispersion and air mobility requirements of military aircraft. It will be applied to winged or platform types—i.e., the Army's flying jeep, to short-range trunk airliners operating directly between city centers, and ultimately to the family's flying automobile. This new kind of engine is specifically developed to increase the operational flexibility of aircraft by reducing their dependence on costly runways. Ryan, Convair, and Bell, to mention a few in this country, have already used existing light gas-turbine engines to prove that VTOL is a practical proposition. No specific VTOL engines have been marketed, but development work is being pushed.

Why are new engine types needed after off-the-shelf equipment has already demonstrated VTOL capabilities? Why can't existing jet engines be made lighter until they are good enough for VTOL? This approach is being used successfully for a number of applications. But there are other important considerations—such as high payload and hovering with economic fuel consumption—that demand new design concepts. In many cases it would be awkward to use large numbers of small lightweight engines to power larger aircraft.

What special characteristics does a good VTOL engine need? The VTOL engine must provide lift in a vertical direction and thrust in a horizontal direction. This output must be produced in the right relative magnitude. The engine must be lightweight and extremely reliable, need little maintenance, and have no severe speed limitation. It must be able to compete economically with the helicopter and other more conventional aircraft. This is a tall order and one that existing power plants cannot satisfy.

Why does a VTOL engine need such widely varying thrust characteristics? Fig. 1 shows what happens to lift, thrust, weight, and drag of a VTOL aircraft during its operation. The typical VTOL transport aircraft has two distinct operating phases, each with unique requirements. There is the take-off and landing phase, with speeds too low for the wings to support the weight. Here the engine must produce lift somewhat

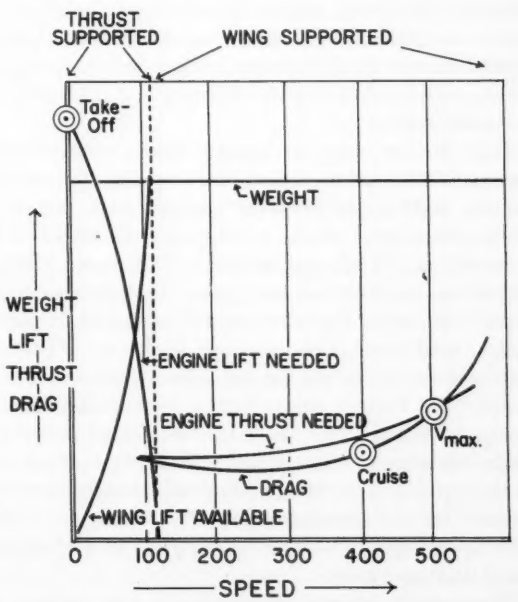

Fig. 1. VTOL THRUST REQUIREMENTS

Shows how speed affects lift, thrust, weight, and drag characteristics of VTOL aircraft which have two distinct phases of operation—phase one, thrust supported during take-off and landing; and phase two, wing supported, after accelerating through stalling speed.

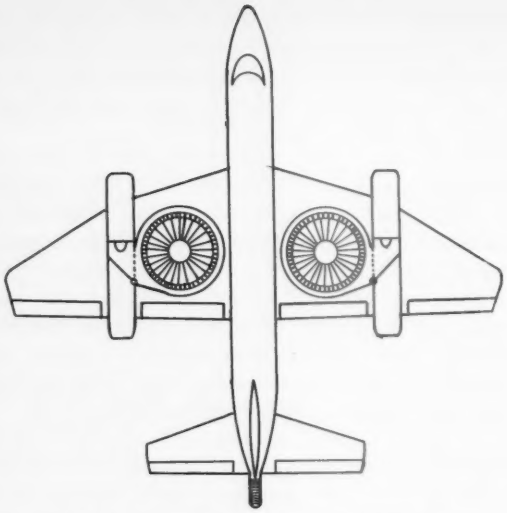

FIG. 2. VTOL PROPULSION SYSTEM

Schematic view of convertible VTOL engines installed in the wing of a VTOL aircraft. The fan takes in air on the top side of the wing and ejects it through control shutters on the underside.

higher than the total gross weight of the aircraft. A forward component for acceleration is obtained through lift vector deflection in the required direction. After accelerating through stalling speed, the aircraft enters the second phase with forward speeds ranging through cruise up to maximum speed. Here wings can support the full weight. During this second phase, the engine produces no lift but only horizontal thrust of the magnitude needed to reach the economic cruise speed and maximum speeds desired.

Here now is the real problem. At take-off, the lift must be somewhat higher than aircraft weight; at cruise conditions, only a small fraction of the weight is needed in the form of thrust. And yet, this engine must produce these widely differing output levels at good efficiencies.

Here is one way to satisfy these requirements. Future VTOL aircraft may be powered by an extremely lightweight turbojet engine, sized for adequate cruise speed at the modest altitude preferred in some typical VTOL applications. This same turbojet engine now performs a dual rule. In hovering flight during take-off and landing, as well as during acceleration to stall speed, the jet nozzle is closed. The hot, high-pressure gases are ducted into a turbine of new design. Its buckets are mounted around the circumference of a fan. The whole unit is located in a duct inside the wing of the aircraft. This fan takes in air on the top side of the wing and ejects it through control shutters on the underside (Fig. 2). There are other drive arrangements possible, such as the more conventional shaft and gear.

The goal is to develop a complete power package of minimum mechanical complexity for which the airframe designer has only to provide a sizable hole in the wing. Gone will be problems connected with tilting wings, tilting engines, slipstream deflectors, and a host of other devices that invariably result from use of standard engines in VTOL aircraft. Decisive progress in VTOL aircraft will be made possible by specially designed engines needed for this unique application.

High Mach Engines

There are three distinct operating limits for air-breathers which restrict the ambient conditions under which they can be used.

First there is an altitude limit beyond which combustion cannot be maintained at good efficiency because of reduced air density. This altitude limitation occurs at increasing heights as flight speeds are increased.

Then there is a speed limitation due to the air pressure inside the engine. At any given altitude we cannot travel faster than a specified maximum without exceeding structural limitations of the engine (and airframe) components.

Finally, the thermal thicket, which is a function of Mach Number, places a third limiting factor on air-breathers. At high Mach Numbers, the ram temperature of the air becomes higher than the materials in the airframe and engine can stand. This Mach limit has been going up steadily during the last few years of turbojet development.

Today engine manufacturers agree that a Mach 4, self-accelerating, turbine-type power plant can be developed with turbine inlet temperatures below 2,000° F. Temperature problems associated with these engines can be met successfully.

Inlet and nozzle design constitutes a major problem in developing high Mach turbomachinery. At low Mach Numbers, engine frontal area is larger than the

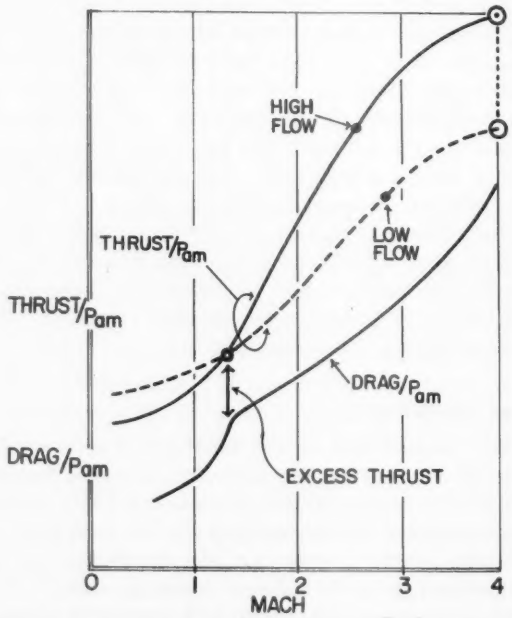

FIG. 3. THRUST AND DRAG CHARACTERISTICS

Shows the relationship between thrust and Mach Number in high- and low-flow design engines. In a high-flow engine, thrust increases faster than the drag of a given airframe.

diameter of inlet duct and nozzle exits. As a result, the engine frontal area is the decisive drag-producing factor.

At high Mach Numbers the ram effect compresses the air before it enters the engine. In these high Mach engines, the inlet capture area exceeds the diameter of the frontal area, thus eliminating compressor diameter as a drag-producing factor. The nozzle now becomes the largest and heaviest part of the engine and constitutes a major design problem. The nozzle must be able to withstand the extreme reheat temperatures, and it must have the variable geometry required to operate efficiently over the wide speed range from static conditions to maximum Mach Number.

High Mach engines with speed capabilities as high as Mach 4.0 have an interesting characteristic which is illustrated in Fig. 3. The graph shows the relationship between thrust and Mach Number in high- and low-flow design engines. It can be seen that, in a high-flow design, the thrust level increases rapidly with Mach Number in a fascinating bootstrap operation. As Mach Number increases, ram pressure goes up forcing an increasing air weight flow through the engine. If the engine inlet duct and nozzle are designed for maximum airflow at high Mach Numbers, the thrust increases faster than the drag of a given airframe. Maximum speed in this case is governed not by the engine's ability to produce enough thrust but rather by its ability to withstand the high thermal stress at the limiting Mach Number.

It is the thrust-Mach Number relationship that the designer can shape to match the airframe requirements.

Fig. 3 also shows that a low-flow engine, equipped with a smaller inlet and nozzle, does not produce so high a thrust level at high Mach Numbers. The engine offers lighter inlet design and a simpler jet nozzle with less need for variable geometry in these components. The low-flow engine has characteristics well matched to high Mach cruise aircraft; the high-flow engine best satisfies requirements for high thrust levels at high Mach Numbers.

The Air-Breathing Boost Engine

The air-breathing boost engine is a specially designed high Mach engine that can serve as a first-stage boost engine for rocket-powered, hypersonic, ballistic, or orbital vehicles. If recoverable air-breathing boost systems are developed to full maturity, they may well prove to be a boon to orbital and space systems of the future by solving some of the pressing problems of economical operation.

The air-breathing boost has compelling advantages that demand attention. Three words—reliability, mobility, recoverability—sum up the advantages of the air-breathing boost. Before examining these advantages, one point remains to be discussed.

It is common knowledge that the turbojet rapidly loses thrust at high altitudes because of lack of air pressure. Fig. 4 sums up the argument for air-breathing boosts. The chart shows thrust of a typical high Mach air-breather plotted over altitude, with temperature and pressure limits indicated.

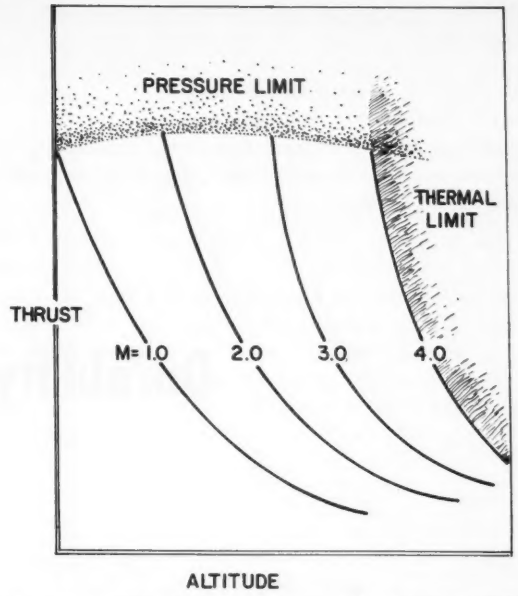

FIG. 4. HIGH MACH THRUST CHARACTERISTICS
A plot of thrust over altitude for a typical high Mach engine with temperature and pressure limits shown. If the vehicle accelerates rapidly enough during a climb, it can use ram pressure to compensate for losses in ambient pressure, thereby maintaining thrust levels at close to the take-off rating over a wide range of altitude.

At a given Mach Number, thrust decreases rapidly with increase in altitude. However, if the vehicle accelerates rapidly enough during a climb to make up for the loss in ambient pressure by ram pressure, the thrust level can be maintained at close to the take-off rating over a remarkable range of altitudes. As engines having capabilities of Mach 4 or more are built with high ram recovery inlets, vast supplies of atmospheric oxygen become available to burn booster fuels. The result—boost power plants with 1,500 sec. of specific impulse burning a cheap and nontoxic propellant as compared with the rocket's 250 to 300 sec. of speeific impulse with fancy, expensive rocket propellants. The rocket, of course, remains unchallenged as the ideal power plant for stages operating at extremely high speeds outside of our atmosphere.

Now, what about the three outstanding advantages of the air-breathing boost—reliability, mobility, and recoverability.

Reliability—The state of the art of turbojets is well advanced, while rocketry is a comparatively young art. Operational problems associated with the rocket are far more complex than those associated with the turbojet.

Mobility—The air-breathing boost system can be ferried from site to site under its own power and is not dependent upon auxiliary means of transportation such as trucking or airlift.

Recoverability—The air-breathing boost vehicle has low fuel consumption. Lift-producing wings can be

(*Continued on page 69*)

The durability of some modern devices —e.g., appendages of rocket engines— depends on complex factors which forbid rational analysis; an empirical basis for a rational approach to the problem, however, can be made.

Durability Under Varying Stress

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THERE ARE SOME modern devices, such as certain appurtenances of rocket engines, which are subjected to such high thermal or other stresses that their durability or length of effective life is often a matter of a few hours. In the present state of art such devices are often very unreliable. For these devices, trustworthy estimates of durability are of prime importance.

The durability of a given piece of equipment may depend almost entirely on the magnitudes of certain measurable stresses. In general, this dependence is so complex as to forbid rational analysis. However, an empirical or experimental basis for such an analysis can be made. It is the purpose of the present paper to present some ideas in this direction.

When a piece of equipment is manufactured in accordance with a system of close quality control, it would be possible to determine by experimental tests highly reliable values of its durability under a continued application of the relevant stresses, kept constant throughout each test. For instance, suppose that the durability of an automobile tire when running over a road of uniform quality was a function only of its velocity. Tests could be made to determine the durability under various constant speeds—e.g., the durability under a constant speed of 30 miles per hour.

One can thus have an adequately large number of values of the durability corresponding to each set of values of the relevant stresses. From these data one could obtain an empirical formula expressing the durability in terms of the magnitudes of these constant stresses. For instance, if there are only two relevant stresses, then the formula in question would be of the form $L = f(x, y)$, where L is the durability in hours and x and y are the values of the constant stresses.

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On the basis of such a formula, one can calculate the durability of the given piece of equipment under conditions where the magnitudes of the stresses vary continuously. This could be of importance in view of the fact that under actual operation (as distinct from a test operation) these stresses often vary and, indeed, vary continuously. It is true that at some testing plants one can perform a test with the stresses varying throughout the test period, but the resulting figure for the durability refers only to the particular time function of the stresses concerned. It would not be directly useful under a different time function.

Naturally, in order to carry out this analysis one needs to know, for any given case, just how these stresses varied with time. The reliability of the final determination will also depend upon just how adequately the formula giving the durability in terms of the magnitudes of the constant stresses represents the true relation between these quantities.

In the present paper, we wish to indicate the theory underlying the functional analysis. In a later paper we hope to consider the statistical aspects of the theory.

The Discrete Case

As this is of minor importance, we shall restrict ourselves to considerations of a single stress. As indicated in Fig. 1, L_1 is the durability in hours under the constant stress x_1; L_2 is the durability under the constant stress x_2, etc.

Let the material be subjected to the stress of magnitude x_1 for l_1 hours, $l_1 < L_1$. It is then immediately subjected to the stress of magnitude x_2 for l_2 hours. It is then immediately subjected to the stress of magnitude x_3 for l_3 hours. This process is continued up to the time the material is subjected to the stress of magnitude x_n, until it fails to function effectively. The problem is to find the total durability or length of life of the piece of equipment involved.

After the piece of equipment has been subjected to the stress x_1 for l_1 hours, it is a fatigued material. We make the plausible engineering assumption that the total number of hours it can stand under the stress x_2, applied immediately, is

$$[(L_1 - l_1)/L_1]L_2 = [1 - (l_1/L_1)]L_2$$

It is, however, subjected to the stress x_2 for only l_2 hours. Then, the total number of hours it can stand under the stress x_3 is

$$\frac{[(L_1 - l_1)/L_1]L_2 - l_2}{L_2} L_3 = \left(1 - \frac{l_1}{L_1} - \frac{l_2}{L_2}\right) L_3$$

After l_3 hours under the stress x_3, it is immediately subjected to the stress x_4. The total number of hours it can stand under the stress x_4 is

$$\frac{[1 - (l_1/L_1) - (l_2/L_2)]L_3 - l_3}{L_3} L_4 = \left(1 - \frac{l_1}{L_1} - \frac{l_2}{L_2} - \frac{l_3}{L_3}\right) L_4$$

It is obvious that the total number of hours that the material can stand under the final stress x_n is

$$[1 - (l_1/L_1) - (l_2/L_2) - \ldots - (l_{n-1}/L_{n-1})]L_n$$

Hence the total durability under the above treatment is

$$l_1 + l_2 + \ldots + l_{n-1} + [1 - (l_1/L_1) - (l_2/L_2) - \ldots - (l_{n-1}/L_{n-1})]L_n \text{ hours}$$

The Continuous Case

We shall first consider the case where the material is subjected to only one stress (Fig. 2).

Let the material be subjected to a continuously varying stress whose magnitude x is given by the differentiable function $F(t)$, where t is the time in hours. Let the durability of the material in hours, corresponding to the stress of magnitude x, constantly applied, be denoted by $f(x)$.

Let the initial value of the stress be x_0 and its final value, x_T. Divide the interval between x_0 and x_T into n equal parts Δx. We first subject the material to the stress x_0 for Δt hours.

$$x = F(t), \quad \Delta x = F'(t)\Delta t, \quad \Delta t = [\Delta x/F'(t)]$$

The remaining life at stress x_0 is then

$$f(x_0) - [\Delta x/F'(t_0)] = f(x_0) - [\Delta x/F'(0)]$$

The material is now immediately subjected to the stress $x_1 = x_0 + \Delta x$. Just as in the discrete case, we assume here that the total number of hours which the material can stand under the stress x_1 is

$$\frac{f(x_0) - [\Delta x/F'(t_0)]}{f(x_0)} f(x_1)$$

We keep the material under the stress x_1 for only $\Delta t = [\Delta x/F'(t_1)]$. We then subject it immediately to the stress x_2, and continue the indicated process.

Let the total number of hours that the material can stand under the final stress x_T be designated by $L(\Delta x)$. It is, obviously, a function of Δx. We define R, the residual life, to be the limit as Δx approaches zero of $L(\Delta x)$.

One may calculate the above limit directly from successive expressions of the type illustrated above. However, it is easier to evaluate this limit by use of the corresponding differential equation. We now derive this equation.

Let the material be subjected to the continuously varying stress $x = F(t)$. Let l be the total available life at the stress x. Of this we use up only $\Delta t = [\Delta x/F'(t)]$ hours. The remaining life at stress x is, then, $l - [\Delta x/F'(t)]$. Then the total available life at stress $x + \Delta x$ is

$$\frac{l - [\Delta x/F'(t)]}{f(x)} f(x + \Delta x)$$

This then is $l + \Delta l$. Hence

$$\Delta l = \frac{l - [\Delta x/F'(t)]}{f(x)} f(x + \Delta x) - l = \frac{l - [\Delta x/F'(t)]}{f(x)} (f + \Delta f) - l$$

$$\Delta l/\Delta x = (l/f)(\Delta f/\Delta x) - [1/F'(t)] - [\Delta f/F'(t) \cdot f(x)]$$

Hence

$$dl/dx = [l/f(x)]\{[df(x)]/dx\} - [1/F'(t)]$$

and

$$\frac{dl}{dx}\frac{dx}{dt} = \frac{l}{f(x)}\frac{df(x)}{dx}\frac{dx}{dt} - \frac{1}{F'(t)}\frac{dx}{dt}\frac{dl}{dt} - \frac{df[F(t)]/dt}{f[F(t)]} - l = -1$$

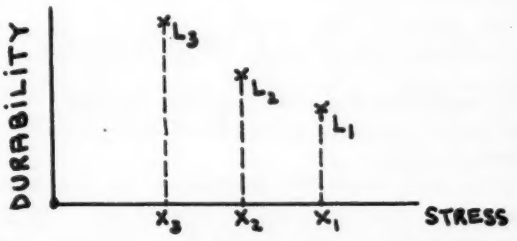

Fig. 1.

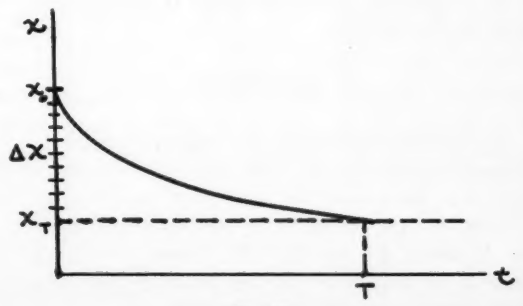

Fig. 2.

This is a linear equation and its solution is given by

$$le^{-\int \frac{df[F(t)]/dt}{f[F(t)]}\,dt} = -\int e^{-\int \frac{df[F(t)]/dt}{f[F(t)]}\,dt} + c$$

$$le^{-\ln f[F(t)]} = -\int e^{-\ln f[F(t)]}\,dt + c$$

$$l\{1/f[F(t)]\} = -\int \{dt/f[F(t)]\} + c$$

or $$l = -f[F(t)]\left(\int_0^t \{dt/f[F(t)]\} + c\right)$$

When $t = 0$, $l = f(x_0)$, so $f(x_0) = -f(x_0)\ (0 + C)$. Hence $C = -1$. Finally, we have

$$l = f[F(t)] - f[F(t)] \int_0^t \{dt/f[F(t)]\}$$

If T is the terminal value of t, then the total residual life at $t = T$ is

$$l_T = f[F(T)] - f[F(t)] \int_0^t \{dt/f[F(t)]\}$$

Whether the material can last through the whole stress course or not depends upon the value of $\int_0^T \{dt \div f[F(t)]\}$.

If $\int_0^T \{dt/f[F(t)]\} < 1$, then the material will last through the course. If, on the other hand, $\int_0^T \{dt \div f[F(t)]\} > 1$, then the material will cease to function effectively before the time $t = T$. If $\int_0^T \{dt/f[F(t)]\} = 1$, then the material will just reach the end of the course.

In the understanding that if the material should survive beyond T hours, it should remain under the henceforward unvarying stress x_T, the total life or durability is given by

$$T + f[F(T)]\left(1 - \int_0^T \{dt/f[F(t)]\}\right) \text{ hours}$$

This expression also gives the total durability in the case that the material fails to function effectively after exactly T hours.

It is more instructive to consider the case where there is no specified terminal value T of t. In this case, the material is subjected to the continuously varying stress $x = F(t)$ until it ceases to function effectively. If h denotes the total durability in hours, then h is given by the equation

$$\int_0^h \{dt/f[F(t)]\} = 1$$

In the foregoing analysis we made essential use of the physical assumption that the total available life at the stress $x + \Delta x$ is equal to the ratio of the remaining life at stress x after the material was subjected to stress x for Δt hours to the total life corresponding to the stress x, all multiplied by the total life corresponding to the stress $(x + \Delta x)$, or in symbols,

$$l + \Delta l = \frac{l - [\Delta x/F'(t)]}{[f(x)]} f(x + \Delta x)$$

As some readers may object to this physical assumption, we shall show that it is equivalent to certain mathematical assumptions. Let

$$l + \Delta l = \frac{l - [\Delta x/F'(t)]}{f(x)} f(x + \Delta x)\phi(x, \Delta x)$$

where $\phi(x, \Delta x)$ is the appropriate "bugger" function of x and Δx.

$$l + \Delta l = \frac{l - [\Delta x/F'(t)]}{f(x)} (f + \Delta f)\phi(x, \Delta x)$$

$$\Delta l = l(\phi - 1) + [(l\Delta f \cdot \phi)/f] - [\Delta x/F'(t)]\,\phi - [\Delta x/fF'(t)]\phi$$

$$\Delta l/\Delta x = [l(\phi - 1)/\Delta x] + l(\phi/f)\,(\Delta f/\Delta x) - [1/F'(t)]\,\phi - [1/fF'(t)]\phi\Delta f$$

We now make the following three mathematical assumptions:

(1) For any x, the function $\phi(x, \Delta x)$ is a continuous function of Δx, i.e., there exists a function $\omega(x)$ such that $\lim_{\Delta x \to 0} \phi(x, \Delta x) = \omega(x)$.

(2) $f(x)$ is a differentiable function of x at every value of x.

(3) l is a differentiable function of x at every value of x.

Inspection of the above equation for $\Delta l/\Delta x$ shows that the above assumptions imply that $\lim_{\Delta x \to 0} (\phi - 1) = 0$, or $\lim_{\Delta x \to 0} \phi(x, \Delta x) = 1$, for every value of x.

This shows that in the incremental equation we may altogether omit the "bugger" function—i.e., assume it to be always equal to unity.

Two Stresses

We shall now consider the case when the piece of equipment is subjected to two different stresses. Let the durability of the material, in hours, corresponding to the stresses of respective magnitudes x and y, constantly applied, be denoted by $f(x, y)$. Let the relations between these stresses and time be denoted by the continuous functions $F(t)$ and $G(t)$. Thus, $x = F(t)$ and $y = G(t)$.

Since x and y are both functions of the time, t, it follows that y is a function of x. This case, then, reduces to the previous one with $f[F(t)]$ replaced by $f[F(t), G(t)]$.

We thus have

$$T + f[F(t), G(t)]\left(1 - \int_0^T \{dt/f[F(t), G(t)]\}\right)$$

as the expression for the total durability, when either the material fails to function just as $t = T$, or, if it reaches $t = T$, it is subjected continuously to the final stresses corresponding to $t = T$ for the remainder of its effective life.

We also have $\int_0^h \{dt/f[F(t), G(t)]\} = 1$ as the expression giving the total length of effective life under the condition that the material is subjected continuously to the variable stresses $x = F(t)$ and $y = G(t)$ for as long as this effective life endures.

The generalization to any finite number of stresses is obvious.

An Example

For purposes of illustration we shall take up the following more or less idealized problem (Fig. 3).

Consider a rocket whose space displacement equations are

$$x = 1{,}500\ (1 - e^{-0.1t}) \quad \text{and} \quad y = 1{,}000(1 - e^{-0.1t}) - 50t$$

in which t is in hours, and x and y are in miles. Assume that the only stress which is relevant to its durability is that induced by the atmospheric pressure.

Assume that the atmospheric pressure is a function only of the elevation and let the functional relation be given by $p = 29e^{-0.5y}$, where y is in miles and p is in inches of mercury.

Assume further that the relation between durability and static pressure is given by $L = \ln 40 - \ln p$. We first determine T. Setting $y = 1{,}000(1 - e^{-0.1t}) - 50t = 0$ we find that $T = 16$ hours.

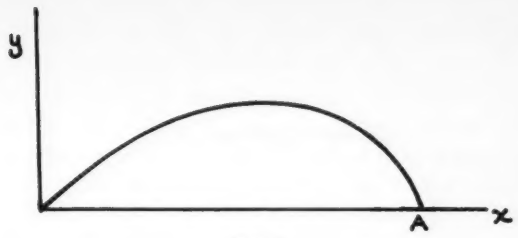

Fig. 3.

$$p = 29e^{25t - 500(1 - e^{-0.1t})}$$

$$L = \ln 40 - \ln 29e^{25t - 500(1 - e^{-0.1t})}$$

$$= 0.322 - 25t + 500 - 500e^{-0.1t}$$

$$= 500.322 - 25t - 500e^{-0.1t}$$

To determine whether or not the rocket will last the whole course—i.e., reach the point A—we have to evaluate the following integral.

$$\phi = \int_0^{16} [dt/(500.322 - 25t - 500e^{-0.1t})]$$

If $\phi < 1$, the rocket will last the whole course. If $\phi > 1$, the rocket will not last the whole course—i.e., it will cease to function effectively before the required $T = 16$ hours.

One notices that the integrand is positive throughout the range. The value of the integral is between 0.2 and 5. The actual value may be found by any of the methods of numerical integration, such as Simpson's method.

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Air-Breathing Power Plants (Continued from page 65)

used to enable the vehicle to glide back home and to land like a conventional aircraft or, in special cases, in a vertical attitude like a tail-sitting VTOL vehicle. Impressive cost-savings are made possible through the use of a recoverable first-stage boost for space operations. No longer is it necessary to rely on a "one-shot" boost system; the air-breathing boost vehicle can be used over and over again. This is particularly significant when space construction projects are contemplated. These projects will require hundreds of supply ships to take building material into orbit. Savings accruing from the use of recoverable boost vehicles can be invested in areas of longer term value, such as more elaborate space stations.

The all-out space race that we are now engaged in will place a severe tax on our economic system. The reliability, mobility, and recoverability advantages of air-breathing boost mean that this boost system can make a necessary contribution to reducing the costs of this race.

Air-breathing boost systems will not become operational in the immediate future. Substantial efforts by engine and airframe designers are required to eliminate every possible ounce of dead weight from the vehicle and its engine. But the day is in sight when an air-breathing boost vehicle will send off a satellite as visualized in Fig. 5 (see p. 62).

Conclusions

The optimum potential of the air-breathing engine has not yet been realized. In the future the air-breathing engine will provide increasingly efficient logistical support; it will free us from the need for acres of runway and open up an entirely new era of mobility for the Armed Services, commercial operators, and ultimately for the individual. Finally, it will serve future space systems as an initial stepping stone, complementing the rocket and other advanced propulsion systems rather than competing with them. The air-breathing boost system will represent an optimized first-stage launching method that will provide a sound economic basis for man's next great adventure—the conquest of space.

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Effects of Gyroscopic Cross Coupling on Missile Automatic Flight Control Systems

Gyro coupling can have a definite detrimental effect on the stability of a missile during maneuvers in which the missile departs from steady level flight.

SINCE THE INCEPTION of automatic flight control systems for aircraft, the displacement gyroscope has served as one of the principal sensing devices for providing a control system reference. This is true because of its characteristic of maintaining a near fixed orientation in space. Thus, three gyroscopes properly located can measure the deviations of a body from an initial orientation of its three axes. By providing control power about these axes, the body can be controlled and stabilized. In the case of an aircraft these controls are generally the elevator, the aileron, and the rudder.

Because the gyro system remains fixed in space while the axes of the aircraft rotate with the maneuvering aircraft, the gyros cannot measure the amount of rotation about the aircraft axes accurately, except in the case of small deviations from the reference position. For this reason, the inaccuracies of the gyro measurements should not seriously affect aircraft which do not maneuver violently. However, we must find out what are the effects of these inaccuracies on present day high performance aircraft.

This paper generally describes the characteristics of the gyros as a function of flight geometry, showing how the outputs of the gyros are influenced by flight attitudes. This influence of attitude on gyro outputs is sometimes referred to as "gyro coupling." Furthermore, some of the effects of gyro coupling on the stabilization and control of aircraft are illustrated and discussed. Finally, some possible remedies for the problems caused by gyro coupling are described and discussed.

Discussion of Gyroscope Measurements

The principle of the gyroscope is well known. It is of interest, however, to examine the gyro outputs in terms of the familiar flight angles. In utilizing a displacement gyro, the spinning mass is mounted in the airframe in such a way as to allow unrestricted movement of the airframe without creating torques on the axis of the spinning mass. This is usually accomplished by mounting the spin axis in a system of two mutually perpendicular frames, referred to as gimbals. The spin axis of the gyroscope is mounted in bearings on the inner gimbal. The inner gimbal, in turn, is mounted in two bearings on the outer gimbal forming an axis of rotation, which is perpendicular to the axis of the spinning mass. Finally, the outer gimbal is mounted in two bearings attached to the airframe forming an axis of rotation perpendicular to the axis of the inner gimbal. The orientation of the spin axis is changed by

Symbols

C_l = rolling moment coefficient, rolling moment/qsb
C_m = pitching moment coefficient, pitching moment/qsc
C_n = yawing moment coefficient, yawing moment/qsb
C_L = lift coefficient, lift/qs
C_y = side-force coefficient, side force/qs
b = wing span, ft.
c = reference moment arm in pitch
m = mass, slugs/cu.ft.
s = operator, d/dt
I = moment and/or product of inertia, slug—ft.sq.
S = reference wing area, sq.ft.
V = velocity, ft./sec.
W = weight, lbs.
α = angle of attack of missile, rad.
β = angle of sideslip of missile, rad.

Subscripts

α = rate of change with respect to α
β = rate of change with respect to β
δ_a = rate of change with respect to δ_a
δ_e = rate of change with respect to δ_e
δ_r = rate of change with respect to δ_r
xx = with respect to x body axis
yy = with respect to y body axis
zz = with respect to z body axis
xz = with respect to xz plane

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This paper was presenfed at the IAS Midwestern Meeting on Guided Missiles, May 12–14, 1958, at St. Louis, Mo.

applying a torque to a gimbal axis causing precession. Gyros have several such torque motors to align and precess the spin axis and gimbals.

The angular deviation of the airframe about the outer gimbal axis (gyro error) can be sensed by a voltage synchro, the rotor of which may be attached to the outer gimbal axis and the stator to the airframe. Bias signals can be combined with the synchro output to achieve input commands.

To describe the outputs of gyros, an axis system must be defined. The rate of change of the aircraft's attitude can be related using a set of Euler axes[1] and Euler angles given by the sequence of rotation of yaw, pitch, and roll

$$\dot{\varphi} = p + (q \sin \varphi + r \cos \varphi)\theta \quad \text{roll} \tag{1}$$

$$\dot{\theta} = q \cos \varphi - r \sin \varphi \quad \text{pitch} \tag{2}$$

$$\dot{\psi} = r \cos \varphi + q \sin \varphi \quad \text{yaw} \tag{3}$$

where p, q, and r are the instantaneous rates of rotation of the airframe about the conventional x, y, and z axes.

Gyroscopes can be used to measure components of these Euler angles (φ, θ, ψ). In order to do this, the gyros can be mounted in a variety of orientations. It is sufficient for illustration to consider here only one popular orientation. To measure pitch angle, θ, the spin axis is mounted vertically and the outer gimbal axis athwartship. To measure roll angle, φ, the spin axis is again mounted vertically with the outer gimbal axis mounted fore and aft. To measure yaw, ψ, the spin axis is mounted athwartship, the outer gimbal axis being mounted vertically. It is shown in reference 2 that this orientation results in the following gyroscopic outputs (given in units of rate of change).

$$\overline{RGE} = p + (q \sin \varphi + r \cos \varphi)\theta \quad \text{roll gyro error} \tag{4}$$

$$\overline{PGE} = q + (p\ PGE - r)\tan \varphi \quad \text{pitch gyro error} \tag{5}$$

$$\overline{YGE} = r + (p\ YGE + q)\tan \varphi' - \dot{\psi}_c \quad \text{yaw gyro error} \tag{6}$$

φ' = angle between spin axis and plane of wings.

$\varphi' \cong \varphi$ if spin axis is not erected to plane of wings. Precession rate is commanded turn rate, $\dot{\psi}_c$.

It is significant to note here the effect of both bank and pitch angles on the gyroscope readings. If the roll and pitch angles are small, the roll gyro measures roll angle (note: it always does) and the pitch gyro measures mostly true pitch rate, and the yaw gyro measures mostly true rate, r. However, it can be seen that when $\varphi = 45°$, the pitch gyro measures not only the pitch rate, q, but the full magnitude of the yaw rate, r, as well. Similarly, the yaw gyro measures the full pitch rate as well as the yaw rate. This is gyro coupling. Note, too, the effect of a pitch angle (or, more specifically, pitch error). Pitch errors cause the pitch gyro to read a component of the roll rate, p. Since the roll rate can be large when compared to the pitch rate, this effect could be significant.

Description of the Gyro Stabilized Aircraft in Motion

In order to study the effect of gyro coupling on the stability and control of automatic flight control systems, the gyro relations were inserted in a system of equations of motion representing an airframe and stabilization system. The following body axes equations of motion can be found in reference 1

$$p = (1/I_{xx})\ [C_{l_B} qsb + (\dot{r} + pq)I_{xz}] \quad \text{roll acceleration} \tag{7}$$

$$q = (1/I_{yy})\ [C_{m_B} qsc + pr(I_{zz} - I_{xx}) - p^2 I_{xz}] \quad \text{pitch acceleration} \tag{8}$$

$$r = (1/I_{zz})\ [C_{n_B} qsb + pq(I_{yy} - I_{xx}) + \dot{p}I_{xz}] \quad \text{yaw acceleration} \tag{9}$$

$$\dot{\beta} = (1/mV)\ [W \sin \varphi + C_{y_B} qs] - r + \alpha p \quad \text{lateral acceleration} \tag{10}$$

$$\dot{\alpha} = (1/mV)\ [W \cos \varphi - C_{z_B} qs] + q - \beta p \quad \text{normal acceleration} \tag{11}$$

The force and moment coefficients for the body axes system are defined as follows

$$C_{l_B} = C_l - c/b\, C_m\beta - C_n\alpha \tag{12}$$

$$C_{m_B} = C_m + b/c\ C_l\beta \tag{13}$$

$$C_{n_B} = C_n + C_l\alpha \tag{14}$$

$$C_{y_B} = C_y - C_D\alpha \tag{15}$$

$$C_{z_B} = C_L + C_D\alpha \tag{16}$$

Where the coefficients C_l, C_m, C_n, C_L, etc., are the conventional stability axis coefficients given by

$$C_l = C_{l_\beta}\beta + C_{l_{\delta r}}\delta r + C_{l_{\delta a}}\delta a + (b/zv)C_{l_p}p \tag{17}$$

$$C_m = C_{m_\alpha}\alpha + C_{m_{\delta e}}\delta e + C_{m_q}(c/zv)q \tag{18}$$

$$C_n = C_{n_\beta}\beta + C_{n_{\delta r}}\delta r + C_{n_{\delta a}}\delta a + (b/zv)\ (C_{n_r}r + C_{n_{\dot{p}}}\dot{p}) \tag{19}$$

$$C_y = C_{y_\beta}\beta + C_{y_{\delta r}}\delta r + (b/zv)\ Cy_p p \tag{20}$$

$$C_L = C_{L_0} + C_{L_\alpha}\alpha + C_{L_{\delta e}}\delta e, \quad C_D = C_{D_0} + C_L{}^2/\pi Ae \tag{21}$$

To define the action of the control surfaces δ_a, δ_e, and δ_r, a typical displacement plus rate type autopilot was assumed to be described as follows

$$\delta_a = (K_{D_\varphi} + K_{R_\varphi}s)\ \overline{RGE} \tag{22}$$

$$\delta_e = (K_{D_\theta} + K_{R_\theta}s)\ \overline{PGE} \tag{23}$$

$$\delta_r = (K_{D_\psi} + K_{R_\psi}s)\ \overline{YGE} \tag{24}$$

where s is the operator $d(\ )/dt$ and K_{D_φ}, K_{D_θ}, and K_{D_ψ} are displacement gains in units of degrees of surface per degree of gyro error in roll, pitch, and yaw. Likewise, K_{R_φ}, K_{R_θ}, and K_{R_ψ} are the corresponding rates or damping gains in units of degrees of surface per degree-per-second of gyro error rate.

This rather detailed description of the system is presented so that some of the effects of gyro coupling may

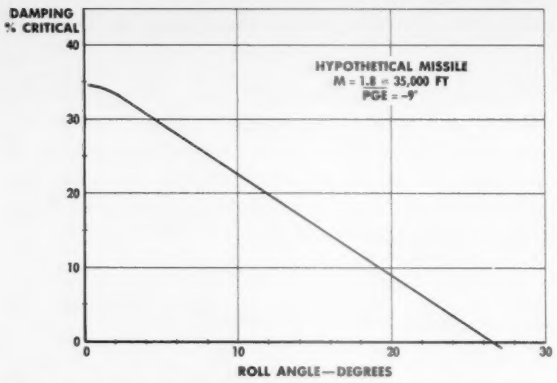

FIG. 1. Effect of roll angle on lateral-directional damping.

be anticipated. For instance, if one inserts the autopilot system with its gyro expressions in the equations of motion (7)–(11), the coupling which results between yaw, pitch, and roll becomes more apparent. A simplified form of the resulting equations becomes

$$\dot{p} = (qsb/I_{xx}) \{ C_{l\delta a}(K_{D\varphi} + K_{R\varphi}s) \times \int [p + (q \sin \varphi + r \cos \varphi)\theta]dt + \ldots \} \quad (25)$$

$$\dot{q} = (qsc/I_{yy}) \{ C_{m\delta e}(K_{D\theta} + K_{R\theta}s) \times \int [q + (p\,\overline{PGE} - r)\tan \varphi]dt + \ldots \} \quad (26)$$

$$\dot{r} = (qsb/I_{zz}) \{ C_{n\delta r}(K_{D\psi} + K_{R\psi}s) \times \int [r + (p\,\overline{YGE} + q) \tan \varphi']dt + \ldots \} \quad (27)$$

It can be seen that the elevator which controls pitch only is a function not only of pitch but of yaw and roll as well. The resulting motion of the airframe will be determined by the phase and magnitude relations between the modes.

Some Effects of Gyro Cross Coupling on the Aircraft in Motion

The automatically stabilized aircraft system, which has just been described, has been studied on the electronic analog computer. The results of the study have provided an understanding of some of the effects of gyro coupling. The results indicate that this coupling manifests itself basically in two ways: (1) the oscillatory characteristics are adversely affected, (2) divergent motions in a normally stable system can be introduced.

The effect of gyro coupling on basic oscillatory stability is pronounced. It was shown earlier that gyro coupling is a function of bank angle, φ, and pitch angle, θ [Eqs. (4)–(6)]. The resulting effect of these variables on a typical aircraft system is shown in Figs. (1) and (2). In Fig. (1), the variation of the damping of the short period motion of the system is shown as a function of bank angle. This typical system, which is well-damped wings level, becomes neutrally stable at bank angles near 28°. In Fig. (2), the effect of pitch angles on damping is indicated. The system is neutrally stable at $-9°$ of pitch during a banked turn.

The mechanics of gyro coupling effects are well illustrated in Figs. (3) and (4). In these figures, the transients introduced by the entry of the aircraft into a banked turn are graphed. In the two figures are shown the components of the outputs of the gyros [see Eqs. (4)–(6)]. In Fig. (3), a right turn with a nose-down attitude is shown. With the nose initially down, the banking of the aircraft increases the negative output of the pitch gyro, causing a negative elevator (trailing edge up) and a pitch-up. The pitch-up, q, is sensed by the yaw gyro, just as the initial yaw rate surge, r, begins to settle out. The pitch-up prolongs and increases the positive reading of the yaw gyro, resulting in positive rudder (trailing edge left) and a negative yaw rate, r. The coupling cycle is completed when the pitch gyro senses the yaw rate and experiences another surge (positive). The resulting motions are of sufficient phase and magnitude to sustain the oscillation. Notice that the initial negative yaw rate induced caused a positive sideslip tending to lift the right wing.

In the case of the right turn with an initial nose-up attitude, somewhat different motions take place (Fig. 4). The initial roll increases the *positive* reading of the pitch gyro, causing a down elevator and a nose-down pitch rate, q. This pitch rate, as before, is sensed by the yaw gyro. In this case, however, the yaw gyro reading is clipped instead of being prolonged and driven negatively. The negative rudder thus obtained

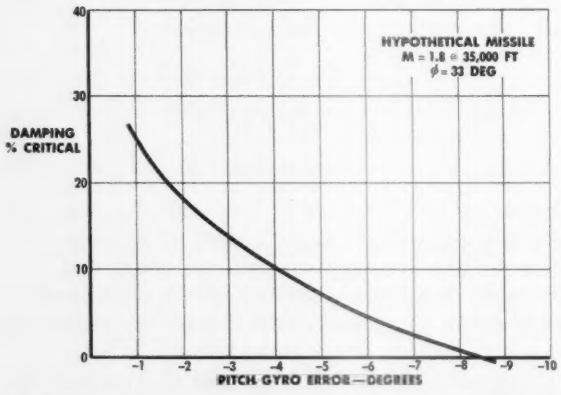

FIG. 2. Effect of pitch gyro error on lateral-directional damping.

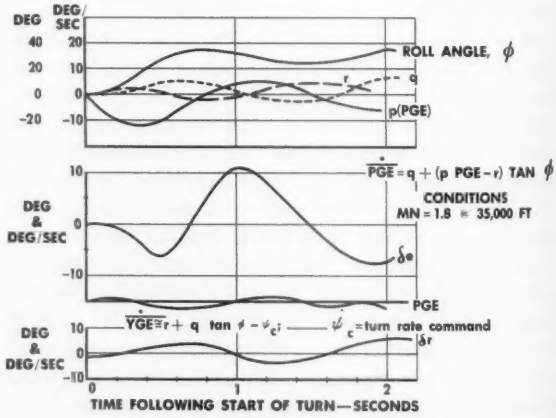

FIG. 3. Turn entry with nose down.

causes not only a positive yaw rate and an increasingly negative pitch gyro reading (plus r gives negative PGE), but the negative sideslip induced increases the right-wing-down bank angle. The result, as can be seen, is a diverging yaw gyro error and a dropping right wing. Also, the frequency of the oscillation is increased at near neutral stability.

Thus, the effects of gyro coupling are seen to be significant and adverse under these conditions. In summary, it is seen that a typical system which exhibited good damping and control in the wings-level condition became unstable in some cases because of gyro coupling.

Possible Remedies for Problems Caused by Gyro Coupling

The results of studies of aircraft with automatic stabilization systems using displacement gyros have indicated the considerable influence of gyroscopic coupling on stability and control. These results have also indicated ways of minimizing the undesirable effects of this coupling. The key, apparently, is to interrupt the coupling at any one or more points. It was found that either one of several methods of diminishing the coupling restored the system to its wings-level performance. The remedies tested took several forms. One method which gave good results was to employ an erection system which aligned the spin axis of the yaw gyro into the plane of the wings. This has the effect of eliminating all inputs to the yaw gyro except yaw rate, r. Another successful method might be labeled "Trigonometric Computers." For example, the sinusoidal output of a synchro, driven as a function of roll angle, φ, may be used to mechanize cosine φ. The output of

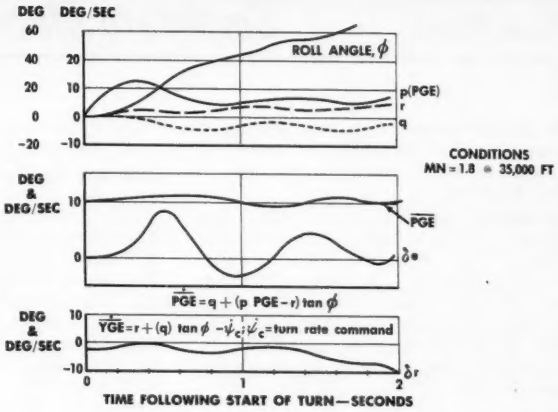

Fig. 4. Turn entry with nose up.

this "cosine synchro" can be used to modify the pitch gyro reading as follows

$$\overline{PGE} = \cos\varphi[q + (p\overline{PGE} - r)\tan\varphi] \approx \dot{\theta}$$

The result of modifying the pitch gyro to read true pitch angle approximately also minimized the effects of gyro coupling.

Thus, the effects of gyro coupling are significant and should be accounted for, but there are available several methods of counteracting these effects.

References

[1] *Dynamics of the Airframe*, BuAer Report AE-61-4, Vol. II.

[2] *An Analysis of the Measurement of Aircraft Attitudes and Angular Velocities by Means of Gyroscopes*, Chance Vought Report No. 8881, February 26, 1954.

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Corporate Member News

• **Aerojet-General Corp.** has announced the appointment of Major Gen. Arthur W. Vanaman, USAF (Ret.), as Assistant to the President.

• **Aeronca Manufacturing Corp.** has formed a new subsidiary—Aeronca-California Corp. The firm also a..nounced the promotion of J. P. Lawler, Washington Representative, to Vice-President.

• **Allison Division, General Motors Corp.,** reports that its prop-jet engines have received CAA approval to begin commercial service with an authorized time before overhaul of 1,000 hours.

• **Aluminum Co. of America** has named James M. Tarter Eastern Traffic Manager.

• **American Airlines, Inc.,** has named H. Don Reynolds to the newly created position of General Traffic Manager in the Sales Department. William H. Baker has been named Director, Selection and Employe Programs, and Mary M. Eckley has been appointed Manager, Food Service.

• **Avco Research Laboratory Division of Avco Manufacturing Corp.** has been scheduled to move into the firm's new $16 million facility at Wilmington, Mass.

• **Bell Aircraft Corp.** . . . Rockets Division reports that it has accomplished the first large-scale rocket thrust chamber firings using liquid fluorine. Research on the new fuel was conducted at the firm's Niagara Frontier Division. Combined with existing fuels, it will increase from 22 to 40 per cent the power output of rocket engines, according to Bell. The company also announced the opening of a new west coast office at 6505 Wilshire Blvd., Los Angeles, to represent the Avionics, Rockets and Space Flight, and Missiles Divisions. . . . Bell Helicopter Corp. has named Martin J. Gould Chief of Electronics Research.

• **Bendix Aviation Corp.** has announced that participation in the USAF Dyna-Soar project will be headed by the Systems Division of the company. Bendix will work on communications systems, telemetering systems, hydraulics, electrical power conversion, cabling, and electrical connectors.

• **Boeing Airplane Co.** has announced the formation of a Systems Reliability and Safety Control group within its Systems Management Office. Colonel Harry G. Spillinger, USAF (Ret.), former Chief, Production Engineering Staff Division in the Directorate of Procurement and Production, Air Materiel Command, has been named Manager of the new group Boeing also announced that teams of engineering service instructors are currently conducting classes in field repair of airplane honeycomb at SAC and AMC bases . . . The Transport Division has delivered the first 707 to Pan American Airways. A CAA provisional-type certificate was granted, the first of this type issued to any United States aircraft.

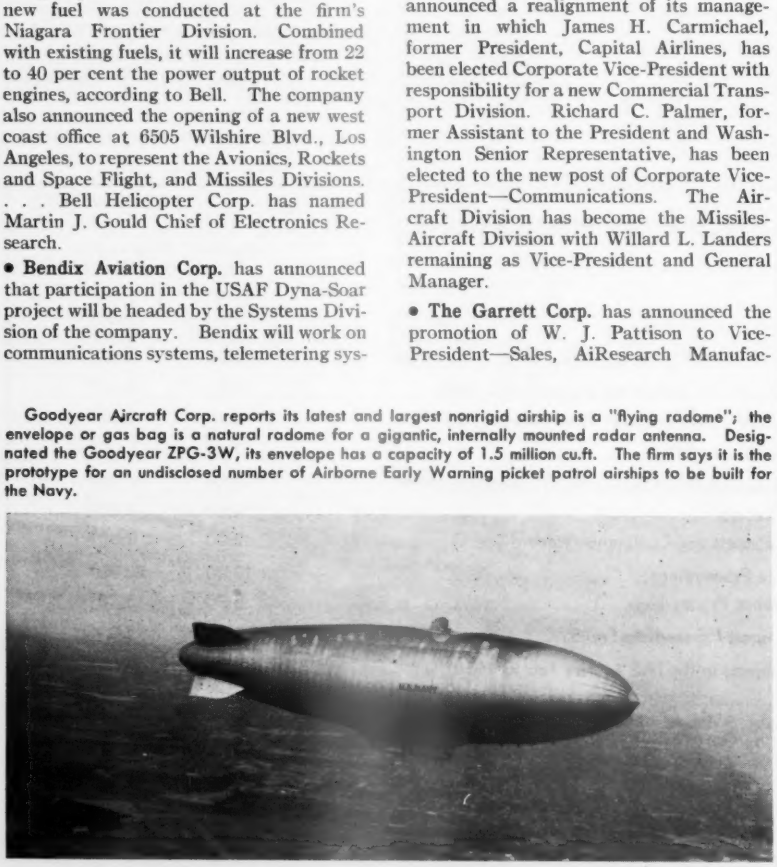
• **Douglas Aircraft Co., Inc.,** reports that its A3D-2P Navy reconnaissance jet made its first flight and is undergoing testing at Edwards AFB. The new plane is powered by two Pratt & Whitney J-57 engines. Wing span is 72.5 ft.; length, 75.5 ft.; and height, 22.8 ft.

• **Fairchild Camera and Instrument Corp.** has announced "purchase of the assets" of Acme Telectronix Division, NEA Service, Inc., Cleveland, Ohio.

• **Fairchild Engine and Airplane Corp.** has announced a realignment of its management in which James H. Carmichael, former President, Capital Airlines, has been elected Corporate Vice-President with responsibility for a new Commercial Transport Division. Richard C. Palmer, former Assistant to the President and Washington Senior Representative, has been elected to the new post of Corporate Vice-President—Communications. The Aircraft Division has become the Missiles-Aircraft Division with Willard L. Landers remaining as Vice-President and General Manager.

• **The Garrett Corp.** has announced the promotion of W. J. Pattison to Vice-President—Sales, AiResearch Manufac-

Goodyear Aircraft Corp. reports its latest and largest nonrigid airship is a "flying radome"; the envelope or gas bag is a natural radome for a gigantic, internally mounted radar antenna. Designated the Goodyear ZPG-3W, its envelope has a capacity of 1.5 million cu.ft. The firm says it is the prototype for an undisclosed number of Airborne Early Warning picket patrol airships to be built for the Navy.



3rd MARS Design Contest

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Russ Henke, Elm Grove, Wis., one of the winners in the 1958 MARS Contest.

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turing Division. Los Angeles; Harry Wetzel, Division Manager, also was named a Vice-President . . . Walter Clark was named Manager, Air Cruisers Division.

• **General Dynamics Corp.** . . . Convair Division reports that a new fuel-defuel station said to service eight USAF jet fighters at one time is in operation at Palmdale, Calif. . . . Stromberg-Carlson Division has announced the appointments of William G. Alexander as Assistant General Manager, San Diego, and Harold F. Field, Director of Marketing, Electronics Division.

• **General Electric Co.** . . . Defense Electronics Division has reorganized its business, the firm announced. The Missile and Ordnance Systems Department is now the Missile and Space Vehicle department; the Ordnance Section has become a separate component—the Ordnance Department—with Gerald A. Hoyt named General Manager. Light Military Electronic Department has announced that Operations Research and Synthesis—with Mark C. Lewis as Manager—has been established as a "formal, primary function." . . . Heavy Military Electronic Equipment Department reports that C. K. Fulton has joined its Missile Defense Equipment Sales staff . . . Aircraft Gas Turbine Division's Small Aircraft Engine Department reports that two new engine test cells have been built in Lynn, Mass., for qualifying and acceptance-testing of the T64 engine.

• **General Precision Equipment Corp.** has announced expansion of its subsidiary and a name change to GPE Controls, Inc., of what had been Askania Regulator Co. . . . Kearfott Co., Inc., reports that it is participating in more than 20 Department of Defense programs. . . . Link Aviation, Inc., has named Rear Adm. John A. Scott (Ret.) Coordinator of Military Requirements.

• **Goodyear Aircraft Corp.** reports that its Human Factors Specialist Anthony J. Cacioppo has been appointed to the USAF-sponsored Committee on Life Sciences, National Academy of Science.

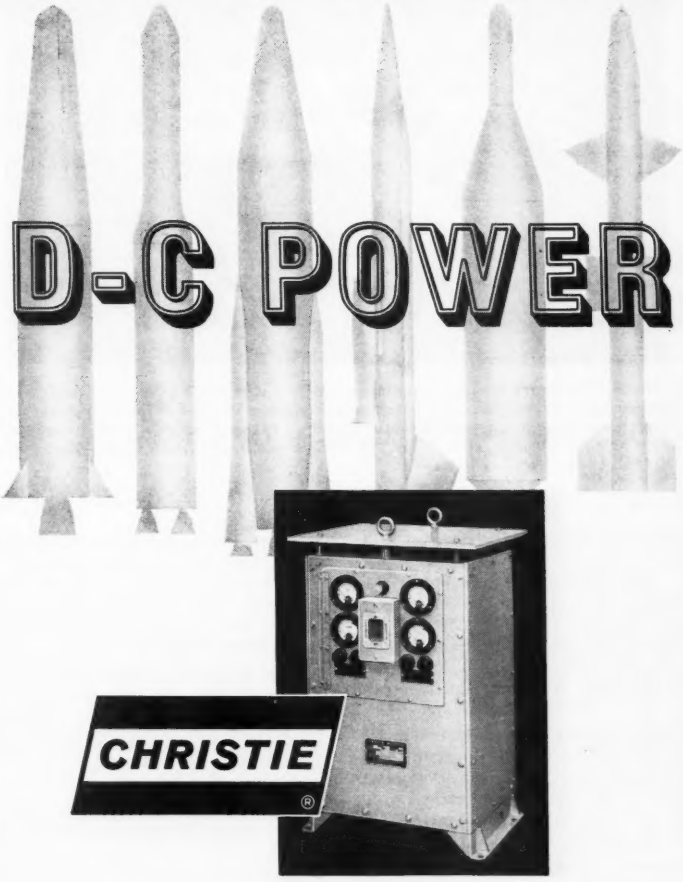
• **Grumman Aircraft Engineering Corp.** reports that its Gulfstream prop-jet executive transport has completed its first flight. Two Rolls-Royce Darts, 2,105 e.s.hp. each, power the plane. Wing span is 78 ft., 6 in.; length—64 ft.; and height —22 ft., 9 in. Gross take-off weight is 31,000 lbs.

• **ITT Laboratories, a Division of International Telephone and Telegraph Corp.,** has named ten new laboratory directors and eleven associate laboratory directors.

• **Lear, Inc.,** has announced the following vice-presidential elections: James P. Brown, General Manager, Astronics Division; James L. Anast, Assistant to the President—Technical Planning; K. Robert Hahn, Corporate Director, Military Products Marketing Services; and Joseph M. Walsh, Assistant General Manager, Grand Rapids Division. Roy J. Benecchi was elected Senior Vice-President. All other officers of the company were re-elected.

• **Lockheed Aircraft Corp.** reported that its Electra transport has been fully certificated by the CAA. . . . Georgia Division has established a Special Products branch

THOR TITAN ATLAS BOMARC POLARIS TALOS



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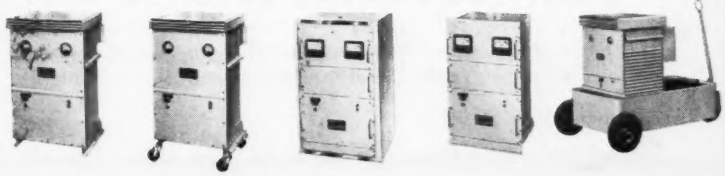

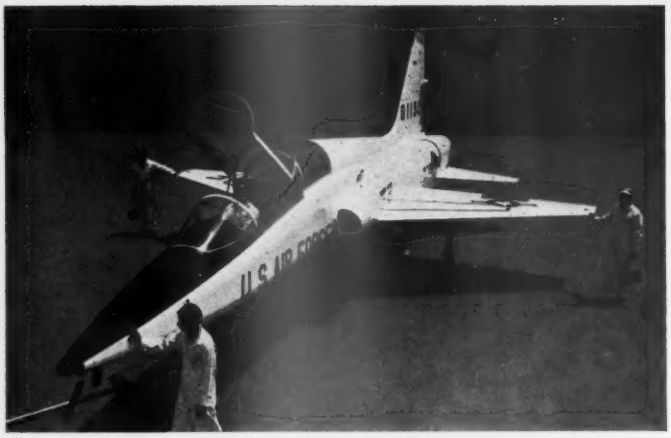

Northrop Aircraft's first T-38 supersonic trainer is said to combine Century Series fighter performance with small size, light weight, and simplicity. Two G-E J85 engines power the aircraft which is said to weigh less than 11,000 lbs. Its overall length is 43 ft.; wing span 25 ft., 3 in.; and height, 11 ft., 11 in. Northrop also is developing a fighter version, the N-156F, of the two-place trainer.

to design, develop, and produce ground support equipment for missiles and aircraft. The division also announced the appointment of J. R. Daniell as Manager, Project Systems branch. Donald J. Murphy, former Project Systems branch head, has been named Assistant Weapon System Manager, Air Force satellite program.

• **Marquardt Aircraft Co.** has announced that its Astro Division will work with the Applied Radiation Corp. in developing the field of ion and other electrical propulsion for space flight applications.

• **The Martin Co.** has announced the appointment of Hugh E. Webber as Manager of Ground Systems at its new guided-missile and electronics center in Orlando, Fla.

• **North American Aviation, Inc.,** has announced the appointment of R. M. Osborn as Project Engineer, Minuteman guidance and control, Autonetics Division.

• **Northrop Aircraft, Inc.,** has announced the election of F. W. Lloyd to the position of Manufacturing Vice-President, Northrop Division.

• **Nuclear Development Corp. of America** has occupied a 63-acre research and development center at Eastview, N.Y. The firm's Pawling, N.Y., Laboratories also are undergoing expansion.

• **Pesco Products Division, Borg-Warner Corp.,** and the Wooster Division, have named John F. Murray Chief Product Engineer. Anthony Kreslik has been named Western Branch Rotating Equipment Project Engineer.

• **The Ramo-Wooldridge Corp.,** Pacific Semiconductors, Inc., has announced that it will build an advanced engineering, production, and administrative center near Los Angeles International Airport; the cost will be $10 million.

• **Republic Aviation Corp.** has appointed Walter Krug Chief Manufacturing Engineer.

• **Ryan Aeronautical Co.** has created two new vice-presidencies with the following appointments: C. A. Stillwagen, Vice-President—Finance, and Treasurer; H. E. Ryker, Vice-President—Operations. B. K. Goodman was advanced to Secretary, and M. K. Smith was promoted to Materiel Director. Hans M. Schiff has been named to the new post of Operations Manager, Torrance Plant. C. E. Mahoney and J. L Richardson have been named Assistant Secretaries of the corporation and will report to the Manager of the expanded Electronics Division, the firm announced.

• **Simmonds Aerocessories, Inc.,** has announced the appointment of Harrison F. Edwards as Technical Operations Manager, and Harlan C. Pringle as Field Operations Manager, Contracts and Service Division.

• **Summers Gyroscope Co.,** engaged in preliminary work on the Quail Project and providing sensing instruments, has announced that it will also work on electronic components and a guidance subsystem for the project.

• **United Air Lines, Inc.,** has named Mervin Claeys to the newly created position of Quality Control Superintendent.

• **United Aircraft Corp.** . . . Pratt & Whitney Aircraft Division reports a successful company 50-hour test on its new J-58 turbojet, a single-spool engine in the 30,000 lbs. thrust class.

• **Westinghouse Electric Corp.** reports that it is producing missile nose cone materials said to withstand re-entry pressure and heat. J. O. Campbell has been named Chicago Area Sales Manager, Apparatus Division.

IAS Sections

Los Angeles Section

Polaris Development Ahead of Schedule

Stanley Burriss, Missile Weapons System Manager, Lockheed Aircraft Corp., discussed **"Development of the Polaris IRBM"** before 190 members on August 14.

He said the Polaris as originally conceived would have been an immense machine; however, from its early development, the design hinged upon predicted and scheduled advances in the state of the art, especially in warhead size reduction and increase in solid propellant engine specific impulse. The program is 1–1½ years ahead of schedule, he said.

Mr. Burriss showed a film of initial test vehicle launches, development facilities, and shipborne equipment. He pointed out the stringent requirements for thrust vector control and power cutoff and the environmental variations unique to the Polaris system.

H. D. MORAN, *Secretary*

NATIONAL NAVAL AVIATION MEETING PROCEEDINGS

The *Proceedings* of the Naval meeting (held in San Diego, Calif., August 5–10, 1957) contains all *unclassified* papers presented at the meeting and is now available.

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. . . current literature of aeronautical engineering and space technology

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Acoustics, Sound, Noise

Sound Propagation in a Fluid Flowing Through an Attenuating Duct. D. C. Pridmore-Brown. *J. Fluid Mech.*, Aug., 1958, pp. 393–406. Study on the propagation of sound in both a constant gradient shear flow and a turbulent shear flow above a flat surface.

Reflection and Transmission of Sound by a Slotted Wall Separating Two Moving Fluid Streams. Appendix—**Details of Computation of Reflection and Transmission Coefficients.** R. L. Barger. *U.S., NACA TN 4295*, June, 1958. 14 pp. 10 refs. Method for obtaining approximate solutions for the steady-state boundary conditions at a slotted-wall boundary. In the analysis the wall with discrete slots is replaced by an equivalent homogeneous boundary.

Noise Characteristics of the Tu-104. I. Razumov, V. Kvitka, and G. Gubkina. (*Grazhdanskaia Aviatsiia*, Feb., 1958.) *The Aeroplane*, May 23, 1958, pp. 721, 722.

Near Noise Field of a Jet-Engine Exhaust. W. L. Howes, E. E. Callaghan, W. D. Coles, and H. R. Mull. *U.S., NACA Rep. 1338*, 1957. 35 pp. 20 refs. Supt. of Doc., Wash., $0.40.

Abacs for the Calculation of the Acoustical Absorption of Perforated Partitions. P. Lienard. (*Acustica*, No. 8, 1958, pp. 86–90.) *Gt. Brit., RAE Lib. Transl. 745*, June, 1958. 8 pp.

Aerodynamics, Fluid Mechanics

Aerodinamika Bol'shikh Skorostei. T. Ligum. *Grazhdanskaia Aviatsiia*, June, 1958, pp. 17–20. In Russian. Discussion covering the physical bases of high-speed aerodynamics, aircraft and power-plant aerodynamic characteristics, take-off and climb, horizontal flight, landing, and stability and control.

Aerothermodynamics

Investigation of the Laminar Aerodynamic Heat-Transfer Characteristics of a Hemisphere-Cylinder in the Langley 11-Inch Hypersonic Tunnel at a Mach Number of 6.8. D. H. Crawford and W. D. McCauley. *U.S., NACA Rep. 1323*, 1957. 21 pp. 18 refs. Supt. of Doc., Wash., $0.25.

Estimation of Turbulent Heat Transfer at the Sonic Point of a Blunt-Nosed Body. Merwin Sibulkin. (*Convair Sci. Res. Lab. RN 7*, Oct., 1957.) *Jet Propulsion*, Aug., 1958, pp. 548–554. 25 refs. Derivation of an equation for the convective heat transfer in terms of conditions at the sonic point of a body.

Avtomodel'nye Resheniia Uravnenii Laminarnogo Pogranichnogo Sloia v Szhimaemoi Zhidkosti pri Nalichii Teploobmena. A. Sh. Dorfman, N. I. Pol'skii, and P. N. Romanenko. *Prikl. Mat. i Mekh.*, Mar.–Apr., 1958, pp. 274–279. In Russian. Derivation of solutions for the equations of laminar boundary layer in a compressible fluid with heat transfer, including a survey and evaluation of previous studies.

Vaporization Into a Hypersonic Laminar Boundary Layer. S. M. Scala. *J. Aero/Space Sci.*, Oct., 1958, pp. 655, 656. USAF-supported discussion on the relationship between the interphase mass transfer, the diffusion rate of vaporizing species, the equilibrium vapor pressure, and the partial pressure; the surface constraints are also presented.

Boundary Layer

Average Properties of Compressible Laminar Boundary Layer on Flat Plate with Unsteady Flight Velocity. Appendix A, B—**Determination of Integrals for Harmonic Oscillations.** F. K. Moore and Simon Ostrach. *U.S., NACA Rep. 1325*, 1957. 12 pp. Supt. of Doc., Wash., $0.20.

Similar Solution of a Laminar Boundary Layer with Rotational Free Stream. F. D. Hains. *J. Aero/Space Sci.*, Oct., 1958, p. 662.

Teplovoi Pogranichnyi Sloi na Vrashchaiushchemsia Diske. L. A. Dorfman. *AN SSSR Dokl.*, Apr. 21, 1958, pp. 1,110–1,112. In Russian. Investigation of the thermal boundary layer on a rotating disc, with a derivation of the equation of turbulent motion for an incompressible liquid.

Flow of Fluids

Nekotorye Vyrozhdennye Okolozvukovye Techeniia. O. S. Ryzhov. *Prikl. Mat. i Mekh.*, March–Apr., 1958, pp. 260–264. In Russian. Study of the transonic motion of an ideal gas represented in the hodograph plane (velocity) by a curve or a surface. Includes determination of a certain class of solutions for plane and axisymmetric flows.

The Effect of Length on the Aerodynamic Characteristics of Bodies of Revolution in Supersonic Flight. Appendix A—**Summary of Theoretical Relations and Spark Range Technique.** Appendix B—**Conversion of the Ballistic Coefficients to Aerodynamic Coefficients.** Appendix C—**Tables of Data.** C. H. Murphy and L. E. Schmidt. *U.S., BRL Rep. 876*, Aug., 1953. 109 pp. 37 refs.

Supersonic Flow Past Quasi-Cylindrical Bodies of Almost Circular Cross-Section. D. G. Randall. *Gt. Brit., ARC R&M 3067* (Nov., 1955) 1958. 17 pp. 16 refs. BIS, New York, $1.17.

Two-Dimensional Subsonic and Sonic Flow Past Thin Bodies. J. B. Helliwell and A. G. Mackie. (*J. Fluid Mech.*, Oct., 1957, p. 93.) *Royal Coll. Sci. & Tech. Dept. Math. Paper (AFOSR TN 58-111) [AD 152019]*, Oct., 1957. 109 pp.

Some Experiments on Effects of Yaw on Boundary-Layer Development in Supersonic Cone Flow. D. G. DeCoursin and W. S. Bradfield. *J. Aero/Space Sci.*, Oct., 1958, pp. 662–664. AFOSR-sponsored study of the effect of small angles of yaw on boundary-layer development on a cone, including turbulent boundary-layer data previously obtained.

The Aerodynamic Properties of the 7-Caliber Army-Navy Spinner Rocket in Transonic Flight. L. E. Schmidt and C. H. Murphy. *U.S., BRL Memo. Rep. 775*, Mar., 1954. 45 pp. 12 refs.

Effect of a Hemispherical Base on the Aerodynamic Characteristics of Shell. R. E. Deitrick. *U.S., BRL Memo. Rep. 947*, Nov., 1955. 35 pp.

Further Numerical Data on Blunt Bodies. H. M. Lieberstein. *J. Aero/Space Sci.*, Oct., 1958, pp. 660, 661.

Ob Obtekanii Pronitsaemykh Konturov. M. V. Tret'iakov. *Prikl. Mat. i Mekh.*, Mar.–Apr., 1958, pp. 220–225. In Russian. Study of the problem covering the potential flow of an ideal fluid past a random smooth, closed, uniformly permeable profile.

A Numerical Method for Evaluating Wave Drag. M. S. Cahn and W. B. Olstad. *U.S., NACA TN 4258*, June, 1958. 13 pp. Development of a numerical method for evaluating von Kármán's wave-drag equation and application to four analytical bodies of revolution. The results yielded are well within the accuracy of the linearized theory.

Oscillation of the Wake Behind a Flat Plate Parallel to the Flow. Sadatoshi Taneda. *Phys. Soc. Japan J.*, Apr., 1958, pp. 418–425. 12 refs. Investigation in a water-tank at Reynolds Numbers 10^2 to 10^3.

Discussions Following the Presentation of Papers on Hypersonics (AGARD Reports 132–147). (*NATO AGARD 11th Wind-Tunnel & Model-Testing Panel, Scheveningen, July 8–12, 1957.*) *NATO AGARD Rep. 132–147*, July, 1957. 43 pp.

On the Flow of a Viscous Fluid Past a Thin Screen at Small Reynolds Numbers. Hidenori Hasimoto. *Phys. Soc. Japan J.*, June, 1958, pp. 633–639.

Nestatsionarnoe Techenie s Teploperedachei v Viazkoi Neszhimaemoi Zhidkosti Mezhdu Dvumia Vrashchaiushchimisia Diskami pri Nalichii Vduva. G. A. Tirskii. *AN SSSR Dokl.*, Mar. 11, 1958, pp. 226–228. In Russian. Investigation of the unsteady flow of a viscous incompressible fluid with heat transfer between two rotating discs in the case of fluid injection.

Variational Approach to Magnetohydrodynamics. Philip Rosen. *Phys. Fluids*, May-June, 1958, p. 251. Application of a dissipation function to magnetohydrodynamics.

Boundary Conditions for the Flow of a Multicomponent Gas. D. E. Rosner. *Jet Propulsion*, Aug., 1958, pp. 555, 556. Analysis considering (a) the phenomenological formulation of the rate at which each chemical specie of an n-component gas is consumed or produced as a result of interaction with a solid surface present in the flow and (b) the resultant boundary conditions on the "steady-state" velocity and concentration fields.

The Production of High Temperature Gas by Magnetic Acceleration. G. S. Janes and R. M. Patrick. *Avco Res. Lab. RR 27*, Mar., 1958. 13 pp. AFOSR-supported development of two experimental devices for investigating the dynamic interactions of high-temperature gases with magnetic fields.

Tables of Radiation from High Temperature Air. B. Kivel and K. Bailey. *Avco Res. Lab. RR 21*, Dec., 1957. 29 pp. 16 refs. USAF-sponsored presentation of radiative emissivity of hot air in the range of temperature from 1,000°K. to 18,000° K. and densities from 10 to 10^{-6} of a normal atmosphere.

Properties of an Ionized Gas of Low Density in a Magnetic Field. S. Chandrasekhar, A. N. Kaufman, and K. M. Watson. *Ann. Phys.*, Nov., 1957, pp. 435–470. 10 refs. Derivation of equations which describe the hydrodynamic properties of an ionized gas in a strong magnetic field and in states close to an initial stationary state. The development is based on the Boltzmann equation in which the effects of collisions between the constituents of the gas are ignored.

Effect of Charge Separation on Plasma Diffusion in a Strong Magnetic Field. A. N. Kaufman. *Phys. Fluids*, May–June, 1958, p. 252.

Supersonic Motion of Vacuum Spark Plasmas Along Magnetic Fields. D. Finkelstein, G. A. Sawyer, and T. F. Stratton. *Phys. Fluids*, May-June, 1958, pp. 188–192. Presentation of velocity measurements and photographs of plasmas. Several coaxial sources which produce somewhat faster plasma streams are described.

Magnetokhimiia Organicheskikh Soedinenii i "Khimicheskie" Svoigi Iadernogo Magnitnogo Rezonansa. Ia. G. Dorfman. *AN SSSR Dokl.*, Mar. 21, 1958, pp. 518, 519. In Russian. Analysis of the magnetochemistry of organic compounds and the "chemical" shifts of nuclear magnetic resonance.

Shock Waves in a Dusty Gas. G. F. Carrier. *J. Fluid Mech.*, Aug., 1958, pp. 376–382. Approximate analysis of the plane steady decelerated flow of a dust-gas mixture. The problem, which has a five-parameter family of solutions, is reduced to a form such that the analysis can be completed by the integration of a first-order nonlinear differential equation and a quadrature.

Ob Udarnykh Volnakh v Sredakh s Proizvol'nym Uravneniem Sostoianiia. G. Ia. Galin. *AN SSSR Dokl.*, Apr. 21, 1958, pp. 1,106–1,109. In Russian. Study of the problem of shock waves in media described by an arbitrary equation of state.

Ob Udare Zhidkosti o Naklonnuiu Stenku Beskonechno Dlinnogo Chastichno Zakrytogo Sosuda. L. S. Ivanova. *Prikl. Mat. i Mekh.*, Mar.–Apr., 1958, pp. 254–256. In Russian. Study of the problem covering the impact of a liquid on the inclined wall of an infinitely long, partially closed container.

O Rasprostranenii Sil'nykh Razryvov v Mnogokomponentnoi Srede. Ia. Z. Kleiman. *Prikl. Mat. i Mekh.*, Mar.–Apr., 1958, pp. 197–205. In Russian. Study of the propagation of shock waves in multicomponent media.

Postroenie Tochnykh Razryvnykh Reshenii Uravnenii Odnomernoi Gazodinamiki i Ikh Prilozheniia. V. P. Korobeinikov and E. V. Riazanov. *Prikl. Mat. i Mekh.*, Mar.–Apr., 1958, pp. 265–268. In Russian. Derivation of exact discontinuous solutions for the equations of one-dimensional unsteady motion of an ideal gas in the presence of shock waves.

Structure of a Centered Rarefaction Wave in a Relaxing Gas. W. W. Wood and F. R. Parker. *Phys. Fluids*, May–June, 1958, pp. 230–241. 10 refs. Theoretical study, both analytical and numerical, of the structure of a centered rarefaction wave in a relaxing ideal gas, neglecting the Navier-Stokes terms in the hydrodynamic equations. The role of the "frozen" sound speed is clarified.

Statistical Study of Turbulence—Spectral Functions and Correlation Coefficients. F. N. Frenkiel. (*France, ONERA RT 34*, 1948.) *U.S., NACA TM 1436*, July, 1958. 116 pp. 18 refs. Translation. Discussion of various possible correlation functions for homogeneous and isotropic turbulence.

On the Spectrum of Turbulence. D. G. Wentzel. *Phys. Fluids*, May–June, 1958, pp. 213, 214. Derivation of the spectrum of turbulence in Chandrasekhar's theory of scattering of electromagnetic waves by a turbulent medium.

Internal Flow

On Pairs of Solutions of a Class of Internal Viscous Flow Problems with Body Forces. Simon Ostrach and L. U. Albers. *U.S., NACA TN 4273*, June, 1958. 21 pp. Discussion of the pairs of solutions to the convection problem. The method of obtaining these solutions is presented, and the influence of various physical parameters on these solutions is discussed.

Kvazistatsionarnoe Istechenie Gaza iz Tsilindricheskogo Sosuda Peremennogo Ob'ema. I. M. Belen'kii. *Prikl. Mat. i Mekh.*, Mar.–Apr., 1958, pp. 279–285. In Russian. Study of the problem of quasi-stationary gas flow from a cylindrical container with varying volume. The importance of this problem in gas power-plant studies and those of internal ballistics is emphasized.

Kolebaniia Reshetki Tonkikh Profilei v Neszhimaemom Potoke. M. D. Khaskind. *Prikl. Mat. i Mekh.*, Mar.–Apr., 1958, pp. 257–260. In Russian. Application of the Haskind method to the analysis of turbulent motion of a liquid and hydrodynamic forces in the case of thin-cascade vibrations, such as would be encountered in turbines.

The Transonic Flow Field of an Axial Compressor Blade Row. J. E. McCune. (*IAS 26th Annual Meeting, New York, Jan. 27-30, 1958, Preprint 792.*) *J. Aero/Space Sci.*, Oct., 1958, pp. 616–626. 10 refs.

Comportement de Grilles d'Aubes de Compresseur de Courbure et d'Allongement Différents. C. Rouffignac. *France, ONERA NT 39*, 1957. 70 pp. 10 refs. In French. Investigation of the behavior of compressor blades having different curvature and aspect ratios.

Performance at Low Speeds of Compressor Rotors Having Low-Cambered NACA 65-Series Blades with High Inlet Angles and Low Solidities. J. C. Emery and P. W. Howard. *U.S., NACA TN 4344*, Aug., 1958. 28 pp.

Design and Tests of a Six-Stage Axial-Flow Compressor Having a Tip Speed of 550 Feet per Second and a Flat Operating Characteristic at Constant Speed. Appendix A—**Derivation of an Equation for the Rate of Change of Work Input with a Change in Axial Velocity.** Appendix B—**Effect of Testing in Freon-12.** W. R. Westphal and J. W. Maynard, Jr. *U.S., NACA TN 4253*, June, 1958. 57 pp.

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INTERNATIONAL AERONAUTICAL ABSTRACTS

A Review of Worldwide Scientific and Technical Literature

Selected and prepared by the IAS Staff from currently released material received in the IAS Library. This research was supported in whole or in part by the Air Force Office of Scientific Research, Air Research and Development Command, United States Air Force.

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AERODYNAMICS, FLUID MECHANICS

Aerothermodynamics

ON THE TEMPERATURE DISTRIBUTION IN THIN FLAT PLATES WITH LAMINAR SUPERSONIC BOUNDARY LAYERS. Magnus Tideman. SAAB TN 39, Jan. 15, 1958. 9 pp. Study of temperature distribution in thin flat plates and presentation of the partial differential equation yielded by the physical problem. Methods of solution are presented, including an approximate procedure and a method for improving the approximation.

MASS TRANSFER COOLING IN A LAMINAR BOUNDARY LAYER IN STEADY TWO-DIMENSIONAL STAGNATION FLOW. A. A. Hayday. Minn. U. Inst. Tech. Dept. Mech. Eng. HTL TN 19 (AFOSR TN 58-337) [AD 154241], Apr., 1958. 36 pp. 13 refs. Analytical investigation of the effects of hydrogen injection on flow and heat transfer characteristics near a stagnation point. A two-dimensional, steady flow field with no chemical reactions taking place, is assumed. Results in the form of velocity, concentration, temperature, skin friction, and surface heat flux variations with injection are presented. It is shown that under the stated conditions a high reduction in the heat transferred into the surface can be expected.

AN EXPERIMENTAL STUDY OF THE EFFECT OF MASS INJECTION AT THE STAGNATION POINT OF A BLUNT BODY. Appendix A - THE MEASUREMENT OF HEAT TRANSFER BY THE TRANSIENT TECHNIQUE. Appendix B - EFFECT OF A THERMOCOUPLE WIRE ON TRANSIENT MEASUREMENTS. Appendix C - TRANSIENT HEAT TRANSFER WITH FLAT PLATE MODEL. H. M. McMahon. GALCIT Memo. 42, May 1, 1958. 132 pp. 38 refs. Investigation covering the effects of the injection of nitrogen and helium coolant gases on the thermal behavior of blunt bodies. Model construction, instrumentation, and test procedure are described. The injection of the coolant gas resulted in a marked reduction in the model equilibrium temperature. For the same mass flow helium is a better choice of coolant than nitrogen. The average heat transfer near the nose of a body was reduced almost to zero by injecting a mass of helium as small as 1/2 % of the mass flow of free-stream air intercepted by the spherical cross-sectional area πR^2. Both methods of injection (straight out of the stagnation point and tangential to the body surface) tend to increase the value of the heat transfer coefficient. The average heat transfer near the nose of the body is reduced almost to zero when a spike having a length to nose diameter ratio of 1.07 is fitted at the stagnation point.

A TECHNIQUE FOR EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER FROM A SURFACE IN SUPERSONIC FLOW AT LARGE SURFACE-TO-FREE-STREAM TEMPERATURE RATIOS. W. S. Bradfield, A. R. Hanson, J. J. Sheppard, and R. E. Larson. Minn. U. Inst. Tech. Dept. Aero. Eng. RAL Res. Rep. 150 (AFOSR TR 58-64) [AD 158252], June, 1958. 24 pp. Description of an apparatus and techniques used to produce a moderately hot surface in a cooling gas stream which is chemically homogeneous and of known composition, and to make measurements of surface temperature, heat flux, and the rate of loss of mass. Preliminary values of local convective and radiative heat transfer at surface temperatures as high as 3,440°R. have been determined. Maximum surface temperatures reached in a stagnant, inert atmosphere have exceeded 6,200°R. and in a Mach 2.3 free jet they have gone as high as 4,700° R. Some studies were also made on the deterioration of graphite surfaces coated with silicon nitride and silicon carbide.

COOLING BY JETS DIRECTED UPSTREAM IN HYPERSONIC FLOW. Antonio Ferri and M. H. Bloom. USAF WADC TN 56-382 [AD 97232], Sept., 1957. 46 pp. 43 refs. Theoretical and experimental study of the effects of mass addition by upstream jet injection under turbulent hypersonic conditions. This investigation is concerned primarily with the behavior of water and air as coolants. An analysis is made of point mass-addition cooling effects in

turbulent flow under hypersonic conditions, and the resulting significant parameters are discussed. The tests were run at a nominal Mach Number of 6 with a stagnation pressure of 600 psia and stagnation temperatures ranging from 1, 200° to 1, 720° R. Comparison between tests and analysis shows that the difference between the heat transfer coefficients (a) under jet cooling conditions and (b) without cooling is seen to be linearly related to the ratio of sink strength to available energy.

ON THE MECHANISMS OF METEORIC ABLATION. Sin-I Cheng. Princeton U. Dept. Aero. Eng. Rep. 427 (AFOSR TN 58-649) [AD 162181], Apr., 1958. 31 pp. 14 refs. Analysis of the ablation phenomenon of meteoric objects entering the atmosphere. The drag and the deceleration encountered by the meteoric body are estimated, and the situation of the convective flow of the liquid layer is discussed. It is shown that the interface under the force field and the relative wind is always unstable and behaves like a saddle point, monotonically diverging exponentially. The possibility of the instability to develop into advanced stages, even though the molten material is extremely viscous, is demonstrated. Interferences are drawn concerning the observed anamolies of the meteoric flashes and some other aspects of meteoric phenomena. A schematic diagram for the different modes of atmospheric ablation of meteoric bodies while entering the atmosphere is given.

A THEORETICAL STUDY OF STAGNATION-POINT ABLATION. Leonard Roberts. US, NACA TN 4392, Sept., 1958. 29 pp. Simplified analysis of the shield mechanism which reduces the stagnation point heat transfer when ablation takes place at the surface. The ablation process considered is that in which the material changes directly from the solid to the gaseous state. The automatic shielding mechanism is discussed and the significant thermal properties of a good ablation are given. The results are given in dimensionless parameters.

MEASUREMENTS IN A SHOCK TUBE OF HEAT-TRANSFER RATES AT THE STAGNATION POINT OF A 1.0-INCH-DIAMETER SPHERE FOR REAL-GAS TEMPERATURES UP TO 7, 900°R. A. P. Sabol. US, NACA TN 4354, Aug., 1958. 15 pp. Determination of heat-transfer rates from measurements of the surface-temperature change with time of a thin-film-platinum resistance thermometer. The test results are presented and compared with the results from theories of Lees and from those of Fay and Riddell. The experimental results obtained give lower heat-transfer rates than both theories but are more compatible with results from the theory of Lees. These test results are also compared with thermocouple data and with the results obtained by the use of similar configurations

Boundary Layer

ON A BOUNDARY LAYER APPROXIMATION TECHNIQUE. Appendix - CONSIDERATION OF THE BOUNDARY LAYER EQUATIONS OF VON MISES. K. T. Yen. Rensselaer Polytech. Inst. Res. Div. TR AE 5802 (AFOSR TN 58-403) [AD 158 206], Apr. 1, 1958. 34 pp. 10 refs. Development of a new boundary layer theory for two-dimensional problems starting from Navier-Stokes equations written in generalized coordinates. Two approximations are developed. The first one, called the P-approximation, applies to boundaries with surface curvature equal to zero. This approximation is essentially equivalent to Prandtl's boundary layer theory. The second boundary layer approximation, called the C-approximation, is developed for the study of the effect of surface curvature. The conditions under which similar solutions exist for the C-approximations are obtained. High speed computing machines must be used to solve the C-approximation.

APPROXIMATE SOLUTIONS OF A CLASS OF SIMILARITY EQUATIONS FOR THREE-DIMENSIONAL, LAMINAR, INCOMPRESSIBLE BOUNDARY-LAYER FLOWS. A. G. Hansen and H. Z. Herzig. US, NACA TN 4375, Sept., 1958. 26 pp. 18 refs. Analysis of boundary layer flows over a flat surface under main-flow streamlines that are translates and representable as infinite series expansions. For the particular case of stream-line shapes described by a power of the distance along the surface from the leading edge, relatively simple expressions are obtained for flow deflection at the boundary surface, limiting stream-line shape, and shear stress at the surface.

ON POSSIBLE SIMILARITY SOLUTIONS FOR THREE-DIMENSIONAL INCOMPRESSIBLE LAMINAR BOUNDARY-LAYER FLOWS OVER DEVELOPABLE SURFACES AND WITH PROPORTIONAL MAINSTREAM VELOCITY COMPONENTS. A. G. Hansen. US, NACA TM 1437, Sept., 1958. 79 pp. 22 refs. Analysis to determine the requirements for the existence of similarity solutions for the following two cases: flow over developable surfaces, and flow over nondevelopable surfaces with proportional mainstream velocity components. Permissible forms are obtained for mainstream velocity components, the square of differential of arc length on the surface, and the similarity parameter. A basic class of surfaces is found from which all other permissible surfaces may be obtained. Necessary and sufficient conditions are found for expressing the ordinary differential equations resulting from the similarity transformation in uncoupled form. The analysis shows that uncoupling is possible only when the surface is developable, and a surface coordinate system characterized by $(ds)^2 = (dx_1)^2 + (dx_2)^2$ is employed.

THEORETICAL DISTRIBUTION OF LAMINAR-BOUNDARY-LAYER THICKNESS, BOUNDARY-LAYER REYNOLDS NUMBER AND STABILITY LIMIT, AND ROUGHNESS REYNOLDS NUMBER FOR A SPHERE AND DISK IN INCOMPRESSIBLE FLOW. Neal Tetervin. US, NACA TN 4350, Sept., 1958. 36 pp. 13 refs. Calculation for a sphere showing that: the boundary layer at the stagnation point of a sphere is much thicker than that on an airfoil, the boundary-layer thickness increases very slowly with an increase in distance from the stagnation point, the boundary layer over the for-

ward portion of a sphere is highly stable at large Reynolds Numbers with respect to the Tollmien-Schlichting type of waves, and the roughness of a given height produces the largest roughness Reynolds Numbers at about 57° from the stagnation point. The calculations for the disc show that the boundary-layer thickness is greatest at the stagnation point and decreases with an increase in distance from this point, the boundary layer is extremely stable with respect to the Tollmien-Schlichting type of waves, and that roughness of a given height produces a given roughness Reynolds Number over a smaller portion of the disc surface than over the surface of the sphere.

INVESTIGATION OF TRANSITION CAUSED BY THE STOPPING OF A FLAT PLATE. J. C. Hegarty. U. Md. Inst. Fluid Dynamics & Appl. Math. TN BN-141 (AFOSR TN 58-627) [AD162157], June, 1958. 33 pp. Investigation of the amplification of the small perturbation due to boundary-layer instability into discrete vortex lines, and their subsequent distortion into a three-dimensional pattern. The intensification of the vortices and the three-dimensional distortion is believed to be a necessary step of the phenomena of transition from laminar to turbulent flow. The results in many respects are in accord with those obtained from the trip wire technique. In addition to the study of the three-dimensionality present in the vortex line, the mechanics of the rotation of the distorted line are also discussed.

EFFECTS OF NOSE ANGLE AND MACH NUMBER ON TRANSITION ON CONES AT SUPERSONIC SPEEDS. K. R. Czarnecki and M. W. Jackson. US, NACA TN 4388, Sept., 1958. 17 pp. Investigation to determine the transition characteristics of a group of smooth sharp-nosed cones varying from 10° to 60° in included apex angle over a Mach Number range from 1.61 to 2.20 and a range of Reynolds Number per foot from about 1.5×10^6 to 8×10^6. Increasing the cone angle is shown to decrease slightly the transition Reynolds Number, whereas the effects of changes in Mach Number and unit Reynolds Number are negligible. When transition occurred within 15 to 20% of the model length from the base there was a dropoff in transition Reynolds Number.

AN EXPERIMENTAL INVESTIGATION OF THE STABILITY OF THE HYPERSONIC LAMINAR BOUNDARY LAYER. Anthony Demetriades. GALCIT Memo. 43, May 15, 1958. 85 pp. 33 refs. Study carried out with the aid of a hot wire anemometer on the stream-wire amplitude variation of both "natural" disturbances and of disturbances artificially excited with a "siren" mechanism. In both cases it was found that such small fluctuations are amplified for certain ranges of the fluctuation frequency and the Reynolds Number, and dampened for others. The demarcation boundaries for the amplification (instability) zone were found to resemble the corresponding boundaries of boundary-layer instability at lower speeds. The amplification rates and hence the degree of "selectivity" of the hypersonic range were found, however, to be considerably lower than those at lower speeds. The disturbances selected by the layer for maximum amplification have a wavelength estimated at about 20 times the boundary-layer thickness, which is appreciably longer than the corresponding wavelengths for low-speed boundary-layer flow.

ON THE LAMINAR BOUNDARY LAYER WITH ARBITRARY PRESSURE GRADIENT AND WALL TEMPERATURE DISTRIBUTIONS. Appendix - THE TRANSFORMED EQUATIONS FOR A SPECIFIC CASE OF STAGNATION POINT FLOW. J. C. Williams, III. USCEC Rep. 40-204 (AFOSR TN 58-583) [AD 162103], July 31, 1958. 17 pp. Analysis of the laminar compressible boundary layer to remove certain restrictions so that the laminar boundary layer with arbitrary pressure gradient and arbitrary wall temperature distribution can be considered with a minimum of simplifying assumptions. The laminar boundary layer equations for a compressible heat conducting gas are first transformed by the Stewartson transformation. The transformed equations are then attacked by the Blasius series procedure which yields a number of pairs of simultaneous ordinary differential equations which, when solved, define the boundary layer on a body with an arbitrary pressure distribution.

SOME PRELIMINARY RESULTS OF VISUAL STUDIES ON THE FLOW MODEL OF THE WALL LAYERS OF THE TURBULENT BOUNDARY LAYER. S. J. Kline and P. W. Runstadler. Stanford U., Dept. Mech. Eng. Rep. MD-3 (AFOSR TN 58-160) [AD 152187], Apr., 1958. 17 pp. 16 refs. Presentation of studies on the flow model in the wall layers of the turbulent boundary layer. Results are summarized for investigation of positive pressure gradients, zero and negative pressure gradients, readjusting zones, and the later stages of transition. In all cases the special visual methods developed for these studies show a definite three-dimensional vortex flow model. The presently available details of this model are described, and a possible interpretation of the physics of the turbulent boundary layer is given.

AN EXPERIMENTAL INVESTIGATION OF THE TURBULENT BOUNDARY LAYER IN SUPERSONIC FLOW AROUND UNYAWED CONES WITH SMALL HEAT TRANSFER AND CORRELATIONS WITH TWO DIMENSIONAL DATA. Appendix I - PREDICTION OF DIMENSIONLESS DISPLACEMENT AND MOMENTUM DEFECT THICKNESSES FOR THE TURBULENT BOUNDARY LAYER ($1 < M_1 < 5$). Appendix II - TURBULENT SKIN FRICTION AND HEAT TRANSFER ON AN UNYAWED RIGHT CIRCULAR CONE AT SUPERSONIC SPEED. Appendix III - THE EFFECT OF PROBE TIP CONFIGURATION ON PROBE FACE EQUILIBRIUM TEMPERATURE. Appendix IV - MAGNITUDE OF EXPERIMENTAL ERRORS. Appendix V - THE TOTAL ENTHALPY THICKNESS RELATION FOR AXIALLY SYMMETRIC CONE FLOW. W. S. Bradfield. Convair Sci. Res. Lab. RR 1, Mar. 15, 1958. 134 pp. 62 refs. Comparison by suitable engineering relations between the cone turbulent boundary layer at constant surface temperature with zero yaw and the two-dimensional turbulent

boundary layer under both compressible ($1 < M < 5$) and incompressible flow conditions. A new type of total temperature boundary layer probe was developed and applied to the measurements of total temperature profiles in the boundary layer of a cone at supersonic speeds. Correlations among velocity profiles, total temperature profiles, momentum thickness, displacement thickness, shape parameter and enthalpy increment for plate, cone, and axial flow cylinder are established; and local values of heat transfer and skin friction coefficients are compared with compressible and incompressible flow plate values.

INTERACTION OF A TURBULENT BOUNDARY LAYER WITH A STEP AT M = 3.85. I. E. Vas and S. M. Bogdonoff. Princeton U. Dept. Aero. Eng. Rep. 295 (AFOSR TN 55-200), Apr., 1955. 58 pp. Investigation to determine the effects of Mach Number upon turbulent boundary-layer separation and to compare the results with those obtained previously at Mach 2.92. The separation and shock wave pattern are determined for steps varying from 1/4 to about two boundary-layer thicknesses. Schlieren and shadowgraph pictures are taken, static pressures are measured ahead of the step, and the pressure ratio to separate the boundary layer is determined. The measured peak pressure ratio agreed with the peak pressure value of Crocco-Probstein. The maximum reverse velocities measured in the separated region are in the order of Mach 0.7.

INTERACTION OF A SHOCK WAVE WITH A TURBULENT BOUNDARY LAYER AT M = 3.85. I. E. Vas and S. M. Bogdonoff. Princeton U. Dept. Aero. Eng. Rep. 294 (AFOSR TN 55-199), Apr., 1955. 31 pp. 15 refs. Experimental investigation covering a pressure ratio across the shock varying from 1.5 to 3.0. It is found that for low incident shock pressure ratios (on the order of 1.8), the pressure along the wall rises smoothly to a maximum value with no separation. For a shock pressure ratio greater than about 2.2, an inflection point occurs in the static pressure distribution and separation is observed. For incident shock pressure ratios equal to or greater than 2.6, the overall phenomenon remains similar, only the scale of the interaction changes. The measured pressure ratio at the separation point is 2.4 as compared to a value of about 2.1 at M = 2.92.

Control Surfaces

THE EFFECTS OF AN INVERSE-TAPER LEADING-EDGE FLAP ON THE AERODYNAMIC CHARACTERISTICS IN PITCH OF A WING-BODY COMBINATION HAVING AN ASPECT RATIO OF 3 AND 45° OF SWEEPBACK AT MACH NUMBERS TO 0.92. F. A. Demele and K. H. Powell. US, NACA TN 4366, Aug., 1958. 57 pp. Experimental investigation to determine the effectiveness of a leading-edge flap in improving primarily the drag characteristics at high subsonic speeds of a wing-body combination having an aspect ratio 3 and 45° of leading-edge sweepback. The experimental equipment is described. Results are presented in graphical form. Aerodynamic data were obtained for flap angles to 16° over a Mach Number range 0.25 to 0.92 at a Reynolds Number of 3.2×10^6, and over a Reynold Number range of 3.2×10^6 to 15×10^6 at a Mach Number of 0.25. In general, the flap had little effect on the lift and static stability of the model. Lift-drag ratios are compared with those of a similar model incorporating conical camber.

Flow of Fluids

SECOND-ORDER SLENDER-BODY THEORY-AXISYMMETRIC FLOW. Appendix A, B - SHORT TABLE OF SLENDER-BODY INTEGRALS. M. D. Van Dyke. US, NACA TN 4281, Sept., 1958. 46 pp. 32 refs. Extension of slender-body theory for subsonic and supersonic flow past bodies of revolution to the second approximation. Methods are developed for handling the difficulties that arise at round ends. Comparison is made with experiment and with other theories for several simple shapes. Complications appear in the case of stagnation points. It is shown that real difficulties arise only for round noses, and that for subsonic flow they can be overcome by comparison with the known solution for a paraboloid. Only a region spanned by the body is considered though the flow upstream and downstream could be treated in the same way.

INVISCID FLOW AROUND A BLUNT BODY OF A REACTING MIXTURE OF GASES. A - GENERAL ANALYSIS. W. Lick. Rensselaer Polytech. Inst. Res. Div. TR AE 5810 (AFOSR TN 58-522) [AD 158335], May, 1958. 52 pp. 33 refs. Description of a general numerical procedure whereby the details of the inviscid flow about a blunt body of a mixture of perfect gases, including the effects of chemical reaction and relaxation, can be calculated. Various simplifying assumptions are made. The fundamental equations and boundary conditions for the inviscid, non-heat-conducting flow are presented. The effects of vibrational relaxation and finite dissociation and recombination rates are included. An inverse method is described allowing the determination of the flow field behind the shock and the corresponding shape of the body. The method of solution and an iteration procedure to increase the accuracy of the computation are discussed. A method of characteristics for two-dimensional flow including vibrational relaxation effects and finite dissociation and recombination rates is developed. The speed of sound is discussed, and a rough analysis of dissociation and recombination rates is made.

FREE-FLIGHT MEASUREMENTS OF PRESSURE DISTRIBUTION AT TRANSONIC AND SUPERSONIC SPEEDS ON BODIES OF REVOLUTION HAVING PARABOLIC AFTERBODIES. C. Kell. Gt. Brit., RAE Rep. Aero. 2605, Apr., 1958. 33 pp. Description of free-flight measurements of the pressure distributions at Mach Numbers from 0.9 to 1.5 and Reynolds Numbers from 31 to 65×10^6 on a series of related afterbodies attached to a common cone-cylinder body of revolution. The experimental results are in reasonable agreement with theoretical values calculated by the method of char-

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acteristics and confirm the usefulness of the supersonic similarity law as a means of predicting drag. Measurements of base pressure are qualitatively in agreement with estimates but not quantitatively, particularly not at low supersonic speeds. Limitations in the experimental technique and in certain cases the occurrence of flow separation are responsible for the discrepancies. Measured boundary-layer displacement thicknesses on the afterbody and estimated values show good agreement.

SHROUD TESTS OF PRESSURE AND HEAT TRANSFER OVER SHORT AFTERBODIES WITH SEPARATED WAKES. M. H. Bloom and Adrian Pallone. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech. Rep. (USAF WADC TN 58-185) [AD 155690], June, 1958. 38 pp. Empirical measurements of pressures and heat transfer rates over three blunt afterbodies of small fineness ratio. Tests were made by means of a shroud technique over a range of Reynolds Numbers closely corresponding to typical flight conditions at Mach Numbers of the order of 20 at stagnation temperatures of 1,300° to 1,600°R. A comparison is made with values obtained from tests of Chapman at Mach Numbers from 2 to 3. The results are presented and compared with each other in terms of nondimensional variables based on flow conditions at the exit shoulder just prior to the afterbody. The pressures are roughly uniform in the afterbody region. The ratio of afterbody pressure to forebody stagnation pressure decreases with increasing stagnation pressure.

NOTE ON THE FORCES ON AN ELLIPTIC CYLINDER MOVING IN A VISCOUS LIQUID AT SMALL REYNOLDS NUMBERS. Yorisaburo Takaisi. Phys. Soc. Japan J., Aug., 1958, pp. 954-959. 11 refs. Discussion of the steady flow of a viscous liquid past an elliptic cylinder at an arbitrary angle of attack on the basis of Reynolds Number expansion, using conformal transformation of the general solutions of Oseen's equation, which are expressed in integral forms. The expansion formulas for the lift and drag coefficients are obtained to the second approximation; they are in perfect agreement with previous results. The procedure gives a practical method of solving Oseen's equation for the two-dimensional slow steady flow of an unbounded viscous liquid past an arbitrary cylindrical body, and a method to study the wall effect upon a cylinder of arbitrary shape moving in a viscous liquid bounded either by a plane wall or by parallel plane walls, provided the mapping function is known for the cylinder.

DRAG DUE TO LIFT OF A NOT-SO-SLENDER CONFIGURATION - APPLICATION OF THEORY. II. R. J. Vidal. USAF WADC TR 57-316, Pt. II [AD 151015], Mar., 1958. 22 pp. Investigation into methods for reducing the supersonic drag due to lift with the aim of improving the supersonic performance of aircraft and missiles. A second-order theory is described which allows the prediction and minimization of the supersonic drag due to lift of rather nonslender wing-body combinations; the restrictions of the theory are reviewed. Methods are presented for applying the theory to aircraft and missile design with appropriate design charts for predicting the chordwise lift distribution of wing-body combinations. The drag due to lift is calculated for three configurations, and the significance of these calculations is discussed.

EXPERIMENTELLE UNTERSUCHUNGEN AN VERSCHIEDEN STARK KONVERGENTEN, SCHLANKEN ROTATIONSKÖRPERN BEI MÄSSIG HOHEN ÜBERSCHALLGESCHWINDIGKEITEN. H. R. Voellmy. ETH Inst. für Aerodynamik, Mitteil. No. 24, 1958. 82 pp. 27 refs. In German. Experimental investigation on various strongly convergent slender bodies of revolution in the case of moderately high supersonic velocities in order to verify the theory derived on the basis of linearized flow equations. Includes description of experimental procedures and installation, as well as determination of boundary layer effect when the viscosity is taken into account.

AN EXPERIMENTAL INVESTIGATION OF VISCOUS EFFECTS ON STATIC AND IMPACT PRESSURE PROBES IN HYPERSONIC FLOW. M. L. Matthews. GALCIT Memo. 44, June 2, 1958. 38 pp. 24 refs. Results of the wind-tunnel investigation indicate that viscous effects on impact pressure probes are important for free stream Reynolds Numbers below 6,000 and $5.4 < M < 5.7$. For $80 < Re < 6,000$ the measured impact pressure is less than the inviscid value. The maximum deviation was 2.3% at a Reynolds Number of 200. For $Re < 80$ the measured impact pressure was greater than the inviscid value. The investigation of static pressure probes at a Mach Number of 5.8 and a free stream Reynolds Number of 16,000 based on the probe diameter shows a very thick and rapidly growing boundary layer over the probe surface. The boundary layer thickness on the 10° cone nose probe is several times that of the probe radius.

STUDIES IN MAGNETO-AERODYNAMICS. I - ONE-DIMENSIONAL FLOWS. II - STABILITY OF LAMINAR BOUNDARY LAYER. H. Li, I. Michelson, and J. Rabinowicz. Odin Assoc. TR 102-1 (AFOSR TR 58-28) [AD 152206], Dec., 1957. 43 pp. Examination of the governing equations of magnetoaerodynamics for the weak interaction approximation. It is found that, for the case where $R_v R_H \ll 1$, it is possible to treat the magnetoaerodynamic interaction as a simple additional body force. The approximate equations for weak interaction are derived and applied to several one-dimensional flows including the propagation of small disturbances and the one-dimensional channel flow. The neutral stability of the boundary layer for a flat plate in the presence of a magnetic field is determined. Results indicate that the application of a magnetic field is unstabilizing in the case of the boundary layer flow with a transverse magnetic field fixed relative to the plate.

SOME PROBLEMS OF MAGNETOGASDYNAMICS WITH ACCOUNT OF FINITE CONDUCTIVITY. G. S. Golitsyn and K. P. Staniukovich. (Zhurnal Teoret. i Exper. Fiz., Dec., 1957, pp. 1,417-1,427.) Sov. Phys.-JETP, June, 1958, pp. 1,090-

1,099. 18 refs. Translation. Analysis of several problems of one-dimensional motion for a medium possessing arbitrary conductivity. It is shown that, if conductivity is taken into account, the equations of magnetogasdynamics become parabolically degenerate. The set of equations is replaced by an approximate but completely hyperbolic set for which the characteristics are found. It is shown that the equations of a stationary one-dimensional flow have a singularity where the flow velocity is equal to the local sound velocity. Conditions of the transition of the flow velocity through this critical value under the action of a magnetic field have been studied. Small oscillations in a conducting medium, shock waves, and the structure of the shock are investigated.

MAGNETOHYDRODYNAMIC-HYPERSONIC FLOW PAST A BLUNT BODY. W. B. Bush. J. Aero/Space Sci., Nov., 1958, pp. 685-690, 728. Analysis of the flow field near the stagnation point of an axisymmetric blunt body in hypersonic flow having a spherical detached shock. A magnetic field is applied to the fluid in the shock layer which is assumed to be incompressible, inviscid, and of constant electrical conductivity. A family of solutions is found for which the body shape is a sphere concentric with the detached shock. For this family of solutions, the standoff distance and pressure relief increase with increasing magnetic field strength. Moreover, with increasing magnetic field strength, the gradient of the tangential velocity at the body decreases.

MAGNETOHYDRODYNAMIC DISTORTION OF A MAGNETIC FIELD DUE TO A UNIFORM FLOW. D. S. Falk. Avco Res. Lab. RR 29, Apr. 30, 1958. 6 pp. Presentation of an exact solution for the distortion of the magnetic field of a straight wire of vanishing diameter, due to the uniform flow of a fluid with constant scalar conductivity, in the limit where the effect of the field on the flow is neglected.

THE MAXIMUM DISTURBANCE GROWTH RATE FOR AN UNSTABLE PLASMA COLUMN. Shobu Kaneko. Phys. Soc. Japan J., Aug., 1958, pp. 947-953. Derivation of a dispersion relation for a self-pinched plasma column enclosed by a conducting wall for the case of a model with both surface sheet current and uniform volume current. The maximum disturbance growth rate for the instability is calculated on the basis of this dispersion relation. It is shown that both the uniform volume current and longitudinal magnetic flux outside the plasma column decrease the stability and make the growth rate faster, the effect of the magnetic flux being larger.

PROPERTIES OF AN IONIZED GAS OF LOW DENSITY IN A MAGNETIC FIELD. IV. S. Chandrasekhar, A. N. Kaufman, and K. M. Watson. Ann. Phys., Sept., 1958, pp. 1-25. Description of a systematic method for solving the Boltzmann equation for the steady states of an ionized gas of low density in a strong magnetic field. The solution is developed as a series in inverse powers of the gyration frequency ω, assuming that the term representing the Lorentz force in the Boltzmann equation dominates all others. The solution is explicitly carried out to the first order in ω^{-1}. Expressions for the drifts which arise in the first order are also obtained.

PRELIMINARY RESULTS OF PLASMA HEATING OF HIGH SPEED AIR FLOW. R. L. Chuan. USCEC Rep. 56-203 (AFOSR TN 58-650) [AD 162 182], July 31, 1958. 8 pp. Presentation of preliminary experimental results from a simple model in which supersonic flow of nominal Mach Number 3.5 and Reynolds Number 2,000 (per cm.) is heated by the decay of a plasma. The process of plasma heating and the experimental apparatus used are described. The maximum stagnation temperature attained is 934°C. at a mass flow of 0.15 gm./sec., which represents at net heat input rate of about 100 watts. Inputs up to 300 watts have been achieved at higher mass flows and higher static pressures.

IONIZATION PHENOMENON OF SHOCK WAVES IN OXYGEN-NITROGEN MIXTURES. S. C. Lin. Avco Res. Lab. RR 33, June, 1958. 23 pp. 15 refs. USAF-sponsored description of an experimental method for studying the ionization phenomenon associated with shock waves in gases. By proper choice of experimental conditions, the method should allow a direct and unambiguous determination of the electron density and the averaged electron-molecule and atom interaction cross section as functions of distance behind the shock front. Some preliminary results obtained for shock waves in a number of oxygen-nitrogen mixtures are presented.

TRANSPORT AND THERMODYNAMIC PROPERTIES IN A HYPERSONIC LAMINAR BOUNDARY LAYER - AEROPHYSICS RESEARCH MEMO 10. S. M. Scala and Ch. W. Baulknight. G-E MOSD TIS 58SD232, Apr. 25, 1958. 49 pp. 31 refs. Calculation of the transport and thermodynamic properties of the components of dissociated air by the use of formulas of statistical mechanics, the Lennard-Jones 6:12 model for the molecular species where appropriate, and the rigid sphere model for the atomic species. These data are then used in performing boundary layer analyses. Some typical results are presented for the case in which dissociated air was treated as a binary mixture of "air atoms" and "air molecules."

COMPRESSIBLE LAMINAR FLOW AND HEAT TRANSFER ABOUT A ROTATING ISOTHERMAL DISK. Simon Ostrach and P. R. Thornton. US, NACA TN 4320, Aug., 1958. 18 pp. Study of flow and heat transfer about a rotating isothermal disc to include the effects of compressibility and property variations. If viscous dissipation is neglected, the compressible problem is correlated to the incompressible problem by assuming linear variations of viscosity and thermal conductivity with temperature. Certain inaccuracies in several previous incompressible solutions are noted and corrected. The effect of compressibility appears as a distortion of the normal coordinate and normal

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velocity component, and as multiplicative factor in the heat-transfer coefficient, the Nusselt Number, and in the expressions for the skin-friction components and torque required to rotate the disc.

A THEORETICAL INVESTIGATION OF THE INTERACTION BETWEEN SHOCK WAVES AND BOUNDARY LAYERS. M. Honda. J. Aero/Space Sci., pp. 667-678. 27 refs. Analysis of a self-inducing type of flow appearing in the interaction process between shock waves and laminar and turbulent boundary layers. The development of the laminar boundary layer is described by using the momentum and energy integral equations on the usual boundary-layer assumptions. The development of the turbulent boundary layer with adverse pressure gradients in incompressible and compressible flow is treated semiempirically. The layer is divided into two regions - inner viscous layer adjacent to the wall and the outer inviscid layer. The growth of the inner viscous layer, following Kármán's dynamic similarity law, is determined by the flow conditions at the inner edge of the outer inviscid layer. The obtained results agree fairly well with those of the experiments.

AERODYNAMICS OF RAREFIED GASES. R. F. Probstein. Brown U., Div. Eng., USAF WADC TN 58-228 [AD 155819], July, 1958. 31 pp. 17 refs. Presentation of some general results relating to the aerodynamics of rarefied gases. The meaning of "rarefied gas flow" is briefly discussed and its parameters introduced. Slip and temperature jump are described, and a new broad classification of the regimes of rarefied gas flow is given. It is pointed out that the "intermediate" regime between where boundary-layer theory and free molecule theory is valid may, except "very close" to the free molecule condition, be treated by continuum theory at least for determining mean aerodynamic coefficients. Free molecule flows are briefly developed, and the concept of a first-order collision regime where the local Knudsen Number is large is examined. It is shown that there exists a similitude for the pressure forces on bodies, for shear, and for heat transfer for a hypersonic free molecule flow.

CONTINUUM THEORY AND RAREFIED HYPERSONIC AERODYNAMICS. R. F. Probstein. Brown U., Div. Eng., USAF WADC TN 58-145 [AD 155587], July, 1958. 27 pp. 12 refs. Prediction of mean viscous aerodynamic characteristics, such as surface heat transfer rate and skin friction, of blunt bodies flying at hypersonic speeds under rarefied gas conditions. At sufficiently high altitudes the appropriate mean free path of the flow becomes too large for the use of boundary layer theory but not large enough that free molecule concepts apply; this "intermediate" regime is studied. The regimes of rarefied gas flow and the limits of continuum theory are defined and the use of the Navier-Stokes equation as a model is proposed. This satisfies overall conservation laws and gives a reasonably accurate picture of all mean aerodynamic quantities. It is shown that in the intermediate regime there are two fundamental classes of problems, a "viscous layer" class and a "merged layer" class, the latter corresponding to a larger degree of rarefaction. For a sphere and cylinder it is shown that new exact solutions of the Navier-Stokes equations can be obtained for both the viscous and merged layer class of problems. Some numerical results are given for illustration purposes.

REVERSE FLOW AND SUPERSONIC INTERFERENCE. J. H. Clarke. Brown U. Div. Eng. (AFOSR TN 58-625) [AD 162155], July, 1958. 42 pp. 26 refs. Presentation of a general analytic proof of the invariance of the drag of an arbitrary spatial distribution of horseshoe vortices and sources under reversal of the undisturbed flow from a volumetric formulation of the momentum theorem of linearized theory. A reverse-flow relation for steady subsonic or supersonic flow is obtained and may be applied as well to arrangements containing bodies whose surfaces are not quasi-cylindrical and whose surface pressures are not linearly related to the perturbation velocity. The reverse flow relation is used to determine the drag and lift of several interfering two-body arrangements in supersonic flow. The invariance of the drag under flow reversal with unchanged geometry is established. The role of edge forces in the result is discussed.

KINEMATICS OF HOMOGENEOUS TURBULENCE. Garrett Birkhoff and J. Kampé de Fériet. J. Math. & Mech., Sept., 1958, pp. 663-703. 14 refs. ONR-supported analysis of the kinematics of homogeneous turbulent velocity fields at a particular time t. The random vector fields (R.V.F.) are considered with q components in p-dimensional space R^p. A procedure to define R.V.F. is described. The connections between admissible and "measurable R.V.F.," and the fundamental properties of the covariance matrix of an admissible random velocity field are established. It is shown that any matrix satisfying a set of conditions on every compact D is the covariance matrix of a unique normal admissible R.V.F. The notions of homogeneity and isotropy are examined. Spectral matrix measures $S_{j,k}(K)$ are introduced. The case of real vector fields is examined, establishing a one-one correspondence between the class of normal admissible real homogeneous R.V.F. and the class of spectral matrix measures satisfying the symmetry condition $S_{j,k}(-K) = S_{j,k}(K)$. The particular case of isotropic, incompressible vector fields is examined. It is concluded that the class of admissible normal R.V.F., having the properties usually assumed in the kinematic theory of homogeneous isotropic turbulence, corresponds one-one to the class of energy distributions $\mathcal{E}(\kappa)$ in wave number space.

DEGENERATE WAVES IN UNSTEADY GAS FLOW. D. Naylor. J. Math. & Mech., Sept., 1958, pp. 705-722. Development of a theory of waves in the unsteady spatial flow of a gas. Flows of the type $q(\lambda, \mu)$, a (λ, μ, t) are investigated; they occupy an intermediate position between the double and triple waves of Giese's theory. The Monge-Ampere equation is integrated and simpli-

fied by taking λ as an independent variable. By a further change of variable the problem is reduced to the integration of a linear equation of the Euler-Poisson type; the general integral of this equation may be written down explicitly. It is shown that no double waves exist in the unsteady plane flow of a gas, and that the lines of constant velocity may not be generated from a fixed straight line. A simplified theory of spatial simple waves is presented, representing flows of considerable generality. The theory of unsteady simple waves in plane flow is extended to three dimensions and progressive waves are described.

Internal Flow

THE INTERNAL FLOW PROBLEM IN AXISYMMETRIC SUPERSONIC FLOW. J. J. Mahony. Royal Soc. (London) Philos. Trans., Ser. A, Sept., 1958. 21 pp. 19 refs. Presentation of a scheme of approximate solution for the steady supersonic flow in a circular duct of slowly varying cross section for the cases when the conventional linearized theory fails. A simple method is also obtained for converting the singular portions of the ordinary solution into a form valid within wave fronts. The problem of an expansive discontinuity in the slope of the duct wall is discussed and the details of the flow are clarified. It is shown that both the velocity and the velocity gradients are finite on the Mach lines where previous theories predicted singularities. Nevertheless, a shock wave is formed in the reflection of the expansion wave from the axis of the duct, no matter how small the initial disturbance.

EFFECT OF SLIGHT MODIFICATIONS OF BOUNDARY ON POTENTIAL TRANSONIC CHANNEL FLOW. Chieh-Chien Chang and Chong-Wei Chu. Minn. U. Inst. Tech. Dept. Aero. Eng. SF Res. Rep. 2 (AFOSR TN 58-526) [AD 158339], June, 1958. 23 pp. 10 refs. Extension of results derived by Chang and Chu in which a symmetrical neighboring solution of Temple-Yarwood transonic channel flow along a slightly less convex but still analytic inner boundary was obtained numerically with the relaxation method. Two types of symmetrical inner channel boundary are considered: a slightly less convex contour and a slightly more convex contour than that of the original Temple-Yarwood flow. First, an unsymmetrical flow solution of the case of the slightly less convex contour is obtained. Secondly, the case of a slightly more convex analytical contour is investigated. Both the symmetrical and the unsymmetrical flow solutions are also obtained with the relaxation method. Physical reasoning indicates that the unsymmetrical potential flow solutions are more likely to occur. It is found that, within the chosen accuracy, potential transonic neighboring solutions exist for both the more convex and the less convex boundaries.

ON THE MIXING OF TWO PARALLEL STREAMS Lu Ting. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 441 (AFOSR TN 58-628) [AD 162158], July, 1958. 26 pp. 12 refs. Derivation, from the compatibility condition of the higher order approximation, of the proper third boundary condition for the mixing of two parallel streams. It is shown that the commonly adopted third boundary condition of balancing of transverse momentum is correct only for the mixing problem of two semi-infinite incompressible streams. For the fulfillment of the proper third boundary condition, the possibility of introducing the similar solution of the Blasius type is examined for various cases.

AN EXPERIMENT ON COMPRESSIBLE FLOW PERTURBATIONS. T. A. d'Ews Thompson and R. E. Meyer. Brown U., Div. Appl. Math. Rep. (AFOSR TN 58-447) [AD 158253], June, 1958. 23 pp. Experimental determination of the effect which a slight tilting of the liners of a supersonic wind-tunnel nozzle has on the Mach Number distribution in the test rhombus. Three contributions to the Mach Number perturbation are clearly distinguished. It is shown that the first-order subsonic and transonic perturbations of the flow may be neglected compared with the supersonic perturbations, and that appreciable effects not accounted for by the first-order theory occur when the flow possesses high local pressure gradients. The appearance of axisymmetrical and three-dimensional shock waves in the flow field is discussed.

Jet Flaps & Wings

THE USE OF BOUNDARY LAYER CONTROL TO ESTABLISH FREE STREAM-LINE FLOWS, BEING AN INTRODUCTION TO THE FREE STREAM-LINE FLAP. D. G. Hurley and N. Ruglen. Australia, ARL Rep. A.109, Apr., 1958. 69 pp. Investigation of a scheme for improving the low-speed properties of wings in the presence of leading edge separation. Boundary layer control is used to reattach the flow to the leading edge of a forward facing flap which is hinged to the upper surface of the wing. Experiments are carried out on a simplified arrangement consisting of two flat plates hinged together at their rear. The edge of the upper plate is rounded and equipped with a single blowing slot. It is found that, when the angle between the plates is 30°, flows could be established which closely resemble the potential solutions. The free streamline envisaged by the theory is replaced in practice by a mixing region whose development can be calculated with reasonable accuracy using mixing length methods.

FLOW ABOUT AEROFOILS WITH SPLIT FLAPS WITH APPLICATION TO CIRCULATION CONTROL BY SUCTION. Appendix A - MODIFICATION OF BASIC FORMULAE IF THE SINK IS PLACED AT A POINT IN THE FLUID. Appendix B - LIMITING FORMS OF THE CUBIC EQUATION. Appendix C - LIFT AND PITCHING MOMENT OF A FLAT PLATE WITH A CONVENTIONAL FLAP. Appendix D - ALTERNATIVE METHOD OF CALCULATING AEROFOIL PARAMETERS. Appendix E - PROOF THAT THE ROOTS OF THE CUBIC EQUATION ARE REAL. L. G. Whitehead, F. Cheers, and P. Mandl. Canada, NAE LR 226, Apr., 1958. 86 pp. Investigation considering the

influence of source or sinks, placed at suitable points, on the aerodynamic characteristics of airfoils with split flaps. A method is described by which an airfoil with a split flap can be transformed into a circle. The theory is then used to calculate the lift obtained from a source placed in the angle between flap and airfoil. Extension is made to the problem of suction as a means of circulation control. Formulas for lift, moment, and center of pressure location are derived and presented graphically as functions of incidence and flap setting. The calculated lift coefficients, although indicating the correct trends in regard to changes in the major variables, were found to be consistently larger than the corresponding experimental values.

EXPLORATORY WIND-TUNNEL INVESTIGATION AT HIGH SUBSONIC AND TRANSONIC SPEEDS OF JET FLAPS ON UNSWEPT RECTANGULAR WINGS. V. E. Lockwood and R. D. Vogler. US, NACA TN 4353, Aug., 1958. 37 pp. Study to determine the lift augmentation of several jet-flap configurations over a Mach Number range from 0.40 to 1.10. Thrust recovery characteristics of some of the thick-wing configurations are also determined. The results indicate that the lift can be increased at any Mach Number by blowing downward through a number of closely spaced holes along and near the trailing edge of the wing. The ratio of induced circulation lift to the lift component of the jet reaction increased with Mach Number up to high subsonic speeds, and then decreased through the transonic speed range. The induced circulation lift was greatly reduced when the jet location was moved from near the trailing edge to the 73% chordline. A jet-augmented flap which used blowing from a slot on the upper surface in combination with a round trailing edge lost its effectiveness at Mach Numbers of 0.60 or greater.

Stability & Control

CHARTS OF PEAK AMPLITUDES IN INCIDENCE AND SIDESLIP IN ROLLING MANOEUVRES DUE TO INERTIA CROSS COUPLING. Appendix I - THE PRODUCT TERMS IN THE EULER EQUATIONS AS CENTRIFUGAL MOMENTS. Appendix II - PHYSICAL EXPLANATION OF THE DIVERGENCIES DUE TO ROLLING. W. J. G. Pinsker. Gt. Brit., RAE Rep. Aero.2604, Apr., 1958. 82 pp. Presentation of charts, based on a series of systematic analog computations, for a general family of rolling and rolling pull-out maneuvers of aircraft subject to inertia cross coupling. The principal parameters governing the stability and response characteristics of aircraft in rolling maneuvers are discussed, and formulas and data are given for their determination.

EFFECTS OF FREQUENCY AND AMPLITUDE ON THE YAWING DERIVATIVES OF TRIANGULAR, SWEPT, AND UNSWEPT WINGS AND OF A TRIANGULAR-WING-FUSELAGE COMBINATION WITH AND WITHOUT A TRIANGULAR TAIL PERFORMING SINUSOIDAL YAWING OSCILLATIONS. William Letko and H. S. Fletcher. US, NACA TN 4390, Sept., 1958. 52 pp. Description of the test procedure, and of the experimental apparatus and wing models used. The results indicate that, except for the complete wing-fuselage-tail configuration, the damping in yaw and the rolling moment due to yawing increase with angle of attack, and at high angles of attack the oscillatory values are considerably greater than the steady-state values. The values of the oscillatory derivatives for the complete-model configuration are considerably greater than the steady-state values through the entire angle-of-attack range. In general, the greatest changes in yawing derivatives with amplitude and frequency occurred in the low range of amplitude and frequency. The results of the present investigation are compared to previous test results.

APPROXIMATE METHOD FOR CALCULATING MOTIONS IN ANGLES OF ATTACK AND SIDESLIP DUE TO STEP PITCHING- AND YAWING-MOMENT INPUTS DURING STEADY ROLL. M. T. Moul and T. R. Brennan. US, NACA TN 4346, Sept., 1958. 42 pp. Derivation of methods which are intended primarily for rolling-velocity conditions in which rolling divergence is not encountered. From the calculated angles of attack and sideslip, preliminary estimates of aircraft loads for design purposes can be made. Motions calculated with the simplified method are compared with exact solutions of the five-degree-of-freedom equations.

Wings & Airfoils

THE THEORY OF A THIN, SLENDER, CONICAL WING WITH THE WING BOUNDARY CONDITION APPLIED AT ITS SURFACE. Appendix - THE EVALUATION OF TWO DEFINITE INTEGRALS. J. H. B. Smith. Gt. Brit., RAE Rep. Aero.2602, Mar., 1958. 31 pp. 14 refs. Calculation of lift and drag forces acting on a thin slender delta wing cambered to form part of the surface of a circular cone, in a type of flow where separation is from the trailing edge only. The boundary condition satisfied by the flow on the wing surface is applied there, instead of on a nearby plane, as is usual in linearized theory. This has relatively little effect on the overall forces on a wing at a given incidence. However, a large discrepancy arises between the overall forces at the incidence for which the singularity in the pressure at the leading edge vanishes, as calculated by the present and by the usual linearized theory. This is particularly important, since it is at this incidence that the type of flow treated is expected to be realized in a physical fluid. The lift-dependent drag factor found is below the usual linearized-theory value for the type of wing at the incidence of no leading edge singularity; and, for a large lift, is below unity, which is the minimum for a trailing vortex sheet which is effectively flat.

KRYLO KONECHNOGO RAZMAKHA V SZHIMAEMOM POTOKE S SIMMETRICHNYM PROFILEM. E. A. Krasil'shchikova. AN SSSR Dokl., May 1, 1958, pp. 51-54. In Russian. Investigation covering the rectilinear motion of a thin wing of finite span with zero angle of attack. The wing is assumed to be of arbitrary shape, but its surface is

symmetrical in relation to the plane of motion. A formula is derived for an arbitrary motion at zero incidence with both subsonic and supersonic velocities. Includes discussion of the case of motion with constant speed and analysis of the problem in a moving system of coordinates.

ANALYTICAL AND EXPERIMENTAL INVESTIGATION OF AERODYNAMIC FORCES AND MOMENTS ON LOW-ASPECT-RATIO WINGS UNDERGOING FLAPPING OSCILLATIONS. D. S. Woolston, S. A. Clevenson, and S. A. Leadbetter. US, NACA TN 4302, Aug., 1958. 25 pp. Comparison of theoretical and experimental results for a rectangular wing of aspect ratio two. Calculated results are also given for three tapered wings of aspect ratio three with varying amounts of sweepback. The calculations are based on a numerical solution of the integral equation of subsonic lifting-surface theory. The experimental techniques employed are essentially those used in previous measurements associated with oscillations. Theory and experiment are generally in good agreement with regard to magnitude of the forces and moments, but differ with regard to phase angle.

AIRFOIL IN A SONIC SHEAR FLOW JET - A MIXED BOUNDARY VALUE PROBLEM FOR THE GENERALIZED TRICOMI EQUATION. Appendix I - JUMP CONDITION. Appendix II - KUTTA-JOUKOVSKY CONDITION. Ch. C. Chang and T. S. Lundgren. Minn. U. Inst. Tech. Dept. Aero. Eng. AR Rep. 1 (AFOSR TN 58-521) [AD 158334], May, 1958. 32 pp. 11 refs. Analysis of small perturbations of a nonuniform two-dimensional flow of a compressible inviscid fluid. It is shown that, for a particular class of Mach Number distributions which are characterized by a sonic line, the linearized compressible shear flow equation can be transformed into the generalized Tricomi equation. The mixed boundary value problem which results from considering perturbations generated by a two-dimensional camber surface is formulated and solved by utilizing the Wiener-Hopf technique.

THEORETICAL AND EXPERIMENTAL ANALYSIS OF A COWLING AS A MEANS OF DRAG REDUCTION FOR AN AXISYMMETRIC CENTER BODY. Marian Visich, Jr., and Anthony Martellucci. Polytech. Inst. Bklyn., Dept. Aero. Eng. & Appl. Mech., PIBAL Rep. 451 (AFOSR TN 58-760) [AD 162273], Aug., 1958. 35 pp. 13 refs. Investigation using nonlinear techniques for the drag reduction of a system containing a large volume per cent length. The design of the body was accomplished by the method of characteristics for axisymmetric irrotational flow for zero angle of attack. The reduction is accomplished by reflecting the conical shock generated from the apex of the centerbody on to the boat-tailed rear part. For the optimum configuration considered, a total drag reduction of 61.8% was measured over the centerbody alone. Comparison of the total drag of the optimum configuration to that of a cone with the same volume and length as the centerbody indicates a reduction of 47%.

NOTES ON THE USE OF ARTIFICIAL DISTRIBUTIONS OF SINGULARITIES IN SUPERSONIC MINIMUM DRAG PROBLEMS. E. W. Graham. Douglas Rep. SM-23022, Dec., 1957. 19 pp. 25 refs. Application of artificial distributions of singularities for the reduction of certain supersonic minimum drag problems in three-dimensional space to two-dimensional potential flow problems. Some of the characteristics of artificial distributions are discussed and illustrated by two examples: (a) a problem of minimum drag for a fixed base area and (b) minimum drag for a fixed volume.

10 ft. x 7 ft. TUNNEL TESTS UP TO M = 0.94 OF NOSE DROOP AND A BLUNT-NOSED NACA 3-00 TYPE SECTION ON A 7 1/2 PER CENT THICK 50° SWEPT WING. A. L. Courtney. Gt. Brit., RAE TN Aero. 2556, Mar., 1958. 44 pp. 24 refs. Description of tests made to improve the subsonic longitudinal stability characteristics of a 50° swept wing of aspect ratio 3.1 by means such as nose-droop, chord extensions, fences, and change of airfoil section. Lift, drag, and pitching and root bending moments were measured at Mach Numbers up to 0.94 and Reynolds Numbers between 1.7×10^6 and 6×10^6. Oil-film flow patterns and the occurrence of an unusual adverse scale effect on the drooped wings at low Mach Number are discussed. It is shown that: (1) none of the section changes give any advantage over the basic RAE 101 section at the highest test Mach Numbers, (2) the drooped-nose sections are superior to the NACA 3-0007.5 section at all Mach Numbers, and (3) the full-span nose-droop is inferior to the part-span droop.

THE CALCULATION OF ORDINATES OF TWISTED AND CAMBERED HIGH-SPEED WINGS. J. M. Watt. Gt. Brit., RAE Rep. M.S. 55, Apr., 1958. 10 pp. Presentation of numerical methods based on linear aerodynamic theory for the evaluation of the chordwise slope of thin wings designed for supersonic flight. The plan form and pressure loading are assumed, and only wings with edges swept back at angles greater than the Mach angle are considered.

EFFECTS OF SOME CHANGES IN BODY LENGTH AND NOSE SHAPE ON THE AERODYNAMIC CHARACTERISTICS OF WING-BODY COMBINATIONS AT SUPERSONIC SPEEDS. S. Tomlin and A. Stanbrook. Gt. Brit., RAE TN Aero. 2542, Feb., 1958. 21 pp. Investigation on three bodies at Mach Numbers of 1.42 and 1.61, tested both alone and in combination with each of two wings. The increments in the forces and moment resulting from the addition of the wing to the body varied little with the different body shapes tested.

HIGH REYNOLDS NUMBER TESTS ON A 70° L.E. SWEEPBACK DELTA WING AND BODY (H.P. 100) IN THE COMPRESSED AIR TUNNEL. R. W. F. Gould and C. F. Cowdrey. Gt. Brit., ARC CP 387, 1958. 23 pp. BIS, New York, $0.63. Presentation of values for lift, drag, and pitching moment coefficients for a wing-body model over a range of Reynolds Numbers from 1×10^6 to 12×10^6

and at incidences up to 42°. Photographs of an oil-titanium oxide mixture on the surface, indicating flow directions, are included. The tests confirm the expectation that there would be no appreciable scale effect on the force and moment coefficients over the range of Reynolds Numbers tested. The surface flow patterns follow the changes generally associated with swept wings and do not reveal any sudden changes with incidence likely to account for the particular shape of the pitching moment curves.

AEROELASTICITY

SOME PANEL-FLUTTER STUDIES USING PISTON THEORY. D. J. Johns. J. Aero/Space Sci., Nov., 1958, pp. 679-684, 715. Analysis of the problem of a flat unbuckled panel and derivation, using the linear piston theory, of the flutter boundaries for rectangular simply supported panels and clamped-edge elliptic panels, for Mach Numbers greater than $\sqrt{2}$. Justification is provided for the use of "static" air forces, neglecting aerodynamic damping, and it is concluded that Ackeret theory is more accurate than piston theory, especially at low Mach Numbers. The results for the rectangular panels agree well with those of other studies using more complex unsteady aerodynamic forces. Flutter equations are solved by applying Galerkin's method to a Rayleigh-type analysis using assumed modes of deformation.

OB USTOICHIVOSTI UPRUGOI PLASTINKI PRI SVERKHZVUKOVOM OBTEKANII. Dun Min-De. AN SSSR Dokl., June 1, 1958, pp. 726-729. In Russian. Application of the linearized theory to the solution of the problem covering the stability of an elastic plate in supersonic flow, reduced to the solution of integral differential equations. The aerodynamic pressure over the surface of the plate is calculated on the basis of Cauchy-Lagrange equation for oscillating wings of infinite span, taking into account the compatibility conditions of oscillations of an elastic plate and a gaseous medium in the immediate vicinity of its surface.

EQUIVALENT CONFIGURATIONS IN FLUTTER ANALYSIS. J. D. C. Crisp. Aero/Space Engrg., Nov., 1958, pp. 55-61. Proposal of configurational equivalence as a means of obtaining qualitative estimates of flutter behavior of configurations derived from a standard system whose characteristics are fully known. The method is illustrated by reference to the binary flutter of a simplified three-dimensional wing-aileron system. It is possible through this example to demonstrate the stabilizing influence of the variation of such parameters as aileron span and position, wing nodal lines of symmetric and antisymmetric modes, aileron twisting modes, and the spanwise position of control actuation.

SUPERSONIC FLUTTER TRENDS AS REVEALED BY PISTON THEORY CALCULATIONS. Holt Ashley and Garabed Zartarian. USAF WADC TR 58-74 [AD 155513], May, 1958. 85 pp. 30 refs. Interpretation of an extensive series of calculations on the bending-torsion, bending-aileron, and torsion-aileron flutter properties of a typical-section airplane wing model presented in tabular form in a previous report. The establishment of the tables is reviewed, and their use for preliminary estimation of high-speed flutter characteristics of lifting surfaces is discussed. A dimensionless number is defined, equivalent to the structural stiffness required for preventing aeroelastic instability of a given typical-section wing flying at a given speed and altitude in the standard atmosphere. In subcases of binary flutter this quantity is shown to depend on 6 to 8 dimensionless parameters. The influence on flutter stability of certain of these parameters is discussed, including Mach Number density ratio parameter, center of gravity location, elastic axis location, frequency ratio, radius of gyration, and airfoil thickness ratio. Results are discussed and presented graphically.

THE EFFECT OF VARIOUS PARAMETERS ON WING TORSION-AILERON ROTATION FLUTTER. Appendix - THE APPROXIMATE SOLUTION OF THE LAGRANGIAN FLUTTER EQUATIONS. A. D. N. Smith. Gt. Brit., RAE TN Struc. 239, May, 1958. 21 pp. Analysis of the effects on wing-aileron rotation flutter of the following parameters: aileron circuit stiffness, aileron massbalance, altitude, and structural damping. It is shown that flutter is prevented either by making the aileron natural frequency higher than that of the wing torsion mode, or by reducing the cross inertia between the modes below a certain critical value. This critical value depends only on three of the coefficients of the Lagrangian flutter equations. It is concluded that the best means of flutter prevention is to rely entirely on adequate circuit stiffness, using a fully duplicated power system, and to dispense with massbalance altogether.

AIRPLANES

Design

SOME NOTES ON PRESSURE-CABIN DESIGN. P. B. Walker. Aircraft Eng., Sept., 1958, pp. 272-276. Discussion of methods of joining the frame and the skin to insure crack-stopping and load distribution. Consideration is also given to the type of window frame to prevent fatigue cracks. It is shown that for design purposes a pressure cabin must be judged as a single entity, with each component considered only in relation to all the rest.

MATHEMATICS

SUR QUELQUES NOUVELLES GENERALISATIONS DE LA THEORIE DES NOMBRES COMPLEXES ET LEURS APPLICATIONS. I - LES NOMBRES COMPLEXES GENERALISES ET LEUR APPLICATION EN GEOMETRIE, ALGEBRE, ANALYSE ET MECANIQUE DES FLUIDES. D. P. Riabouchinsky. France, Min. de l'Air PST 343, 1958. 166 pp. 36 refs. SDIT, 2, Av. Porte-d'Issy, Paris 15, Frs. 2,750. In French. Generalization of the theory of complex numbers and their application to problems of geometry, algebra, analysis,

and fluid mechanics. The latter include subsonic, transonic, and supersonic motion of a compressible fluid.

MECHANICS

SOME RECENT ADVANCES IN THE MECHANICS OF TERRESTRIAL FLIGHT. Angelo Miele. Jet Propulsion, Sept., 1958, pp. 581-587. 71 refs. Survey of problems in the mechanics of terrestrial flight with particular regard to the optimization of the trajectories of both quasi-steady and nonsteady flight. The optimum problems of quasi-steady flight are amenable to treatment by the ordinary theory of maxima and minima. For the case where the aircraft configuration is given, a new and general determinant equation is presented. A general solution is also presented for the aerodynamic configuration which is the best for optimizing arbitrary performance. Nonsteady flight mechanics lead to minimal problems falling in the domain of the problems of Bolza, Mayer, and Lagrange of the calculus of variations. The recent variational literature is reviewed with particular regard to the programing of the lift distribution, thrust modulus, and thrust direction. It is concluded that there is an inmediate need for improved methods for integrating the system of Euler equations and constraining equations, and for solving the associated boundary problems.

METEOROLOGY

Upper Air Research

O NEKOTORYKH REZUL'TATAKH OPREDELENIIA ELEKTRONNOI KONTSENTRATSII VNESHNEI OBLASTI IONOSFERY PO NABLIUDENIIAM ZA RADIOSIGNALAMI PERVOGO SPUTNIKA ZEMLI. Ia. L. Al'pert, F. F. Dobriakova, E. F. Chudesenko, and B. S. Shapiro. Uspekhi Fiz. Nauk, June, 1958, pp. 161-174. In Russian. Presentation of results on the determination of electron concentration in the outer region of the ionosphere based on observations of radio signals from the first artificial satellite. A method for analyzing the satellite data, based on the determination of the time of "radio-rise" and "radio-setting" of the satellite, is presented and the obtained results are evaluated. Includes examination of the trajectory of radio waves in the ionosphere, calculation of the receiving distance, and determination of the density of the interplanetary gas.

MISSILES

ON THE OPTIMUM TRAJECTORY OF A ROCKET. R. R. Newton. Franklin Inst. J., Sept., 1958, pp. 155-187. 10 refs. Examination of the nature of the mathematical problem posed by optimizing a rocket trajectory, the possibility of auxiliary or "iso-perimetric" conditions being stressed. It is shown that an optimum trajectory may be found if no more than four (in a two-dimensional theory) auxiliary conditions are specified. The trajectories to give maximum range and to put a satellite into an orbit most efficiently are calculated. The study was limited to the problem in vacuum, but a procedure for determining the proper correction in air is also outlined. The effects of air on the satellite problem are discussed only qualitatively.

PROBLEMS IN THE DEVELOPMENT OF A GUIDED WEAPON. J. Clemow. RAeS J., Sept., 1958, pp. 663-673. Discussion covering the organization of a guided-weapon development program, stressing the importance of trials and methods of conducting them. Such factors as the assessment and design study, improvement of the aerodynamic response, and the cross-coupling effects are considered along with problems of fast response and stability.

PERFORMANCE ESTIMATION OF THE COOLANT-FUEL SYSTEM. L. Greiner, J. Rabinowicz, and A. Zuckerman. Odin Assoc. TR 100-1 (AFOSR TR 58-43) [AD 154150], Dec., 1957. 35 pp. 13 refs. Summary of a preliminary investigation of a new method for preventing overheating of the external structure of a rocket powered aircraft or missile traveling at hypersonic speeds within the atmosphere. Rocket fuel is used as a coolant; it maintains the structure at manageable temperatures and results in a significant thrust augmentation of the rocket engine. By judicious selection of fuels heat absorption of 1,200 to 4,000 BTU/lb. can be achieveded with temperature rise from 77° to 1,500°F., with corresponding augmented specific impulse of 300 to 400 sec. A preliminary evaluation of the flight performance of this system is carried out, and a method for determining the flight envelope for a missile configuration is presented. Cruise range calculations indicate that ranges of a few thousand miles are feasible.

NAVIGATION

UNE MECANIQUE DES SYSTEMES INERTIAUX; UNE THEORIE DE LA GRAVITATION; UNE MECANIQUE DES PETITES DISTANCES. O. Onicescu. J. Math. & Mech., Sept., 1958, pp. 723-740. In French. Presentation of a new system of mechanics, being a direct extension of the Newtonian system, applicable both to high speeds and small distances. The mechanics of a material point in inertial motion are first established; several axioms and a principle of motion are then stated. In this system of mechanics the theory of inertia is at the same time a theory of gravitation. For current speeds and distances the equations obtained are reduced to Newtonian equations.

POWER PLANTS

Jet & Turbine

SOME INVESTIGATIONS IN THE FIELD OF BLADE ENGINEERING. D. Blackwell. (RAeS Symposium on Aircraft Propulsion, Mar. 3, 1958.) RAeS J., Sept., 1958, pp. 633-646. Examination of the mechanism of blade failure, blade materials, and quality control. A diagrammatical representation of the field of blade engineering is made. Compressor and turbine blade-form failures, as well as root fixing failures, are analyzed; the mechanism of blade vibration is studied. Experimental studies

to determine compressor blade damage are described. The derivation of design data from laboratory mechanical tests and blade fatigue test results are discussed and represented graphically. The selection of blade materials and heat-treatment techniques are described.

EXHAUST NOZZLES FOR SUPERSONIC AIRCRAFT. H. Pearson. RAeS J., Sept., 1958, pp. 658-662. Evaluation of various exhaust nozzles for supersonic aircraft. The advantages and limitations of the ordinary convergent nozzle, the convergent-divergent nozzle, the variable convergent-divergent nozzle, and the ejector nozzle for expanding the exhaust efficiency are described. A typical installation of an ejector nozzle is shown diagrammatically and thrust increases due to the proper nozzle selection are presented. The matching of air intakes and nozzles is discussed. It is concluded that by practical forms of nozzle a thrust increase at M = 2.5 of about 30% is achievable with known test data.

FUEL SYSTEMS FOR SUPERSONIC ENGINES. E. A. Simonis. RAeS J., Sept., 1958, pp. 654-658. Description of the supply and control of fuel to the main engine combustion chamber. A diagrammatic layout of a supersonic aircraft engine is given, and a flight plan for supersonic fuel systems is proposed. The use of fuel for cooling purposes is considered; problems in fuel vapor pressure, the effects of dirty fuels, and the ability to withstand icing are described. Various injection methods, such as the spill burner system, are analyzed, and a comparative study of their respective advantages is made.

Rocket

RAKETNYE DVIGATELI. I - RABOCHII PROTSESS I KOEFFITSIENTY POLEZNOGO DEISTVIIA ZhRD. N. E. Konovalov. Vestnik Vozdushnogo Flota, June, 1958, pp. 44-52. In Russian. Discussion of the basic design and operating characteristics of liquid rocket power plants, including such factors as fuel consumption, pressure at the exit, kinetic energy, and the effect of various nozzle design parameters and overall vehicle characteristics.

AN ANALYTICAL STUDY OF TURBULENT AND MOLECULAR MIXING IN ROCKET COMBUSTION. Appendix - ANALYTICAL EXPRESSION FOR THE RIPPLE FACTOR IN MODEL 1. D. A. Bittker. US, NACA TN 4321, Sept., 1958. 22 pp. 13 refs. Approximate calculations of the diffusion of gases performed to evaluate the importance of gaseous mixing in rocket combustion. Mixing lengths for two simplified diffusion models are calculated for various turbulence conditions. Results are independent of any particular propellant combination. With sources in a single injection plane, mixing occurs in less length than is needed for evaporation of typical engine sprays. When downstream sources are used to simulate vaporization within the chamber, mixing is more significant. Calculations only indicate the magnitude of the effect since the models used are greatly simplified.

EROSIVE BURNING OF A COLLOIDAL SOLID PROPELLANT. J. A. Vandenkerckhove. Jet Propulsion, Sept., 1958, pp. 599-603. Study made in an attempt to obtain physical understanding of erosive burning of a solid propellant, taking into account the flame structure. At low pressure the burning rate of a double base propellant is entirely determined by the heat transfer within the fizz zone with no heat exchanged from the high temperature flame zone. Therefore it has been assumed that erosive burning is due to the effects of turbulence within the fizz zone, the threshold velocity corresponding to the moment when incipient turbulence reaches the boundary of the fizz zone. By doing so it has been possible to calculate an erosion coefficient in close agreement with the experimental values.

PROPELLANT VAPORIZATION AS A CRITERION FOR ROCKET-ENGINE DESIGN; CALCULATIONS OF CHAMBER LENGTH TO VAPORIZE VARIOUS PROPELLANTS. R. J. Priem. US, NACA TN 3883, Sept., 1958. 36 pp. Calculation of vaporization rates for drops of n-heptane, ammonia, hydrazine, oxygen, and fluorine. The per cent propellant vaporized is correlated with an effective chamber length for various spray conditions and various engine design and operating parameters. The results show that the effective chamber length required to vaporize a given high percentage of propellant is the shortest with oxygen and increases for fluorine, heptane, ammonia, and hydrazine in that order.

PROPELLERS

EFFECT OF ADVANCE RATIO ON FLIGHT PERFORMANCE OF A MODIFIED SUPERSONIC PROPELLER. J. B. Hammack and T. C. O'Bryan. US, NACA TN 4389, Sept., 1958. 20 pp. Results of a flight investigation to determine the aerodynamic characteristic of a supersonic propeller modified by the incorporation of higher than optimum advance angles. The propeller was designed for a forward Mach Number of 0.95, an advance ratio of 3.2, and a power coefficient of 0.42. The efficiency of the propeller is approximately 79% at a Mach Number of 0.95. At lower Mach Number the efficiency is higher, being 85% at a Mach Number of 0.75. The departure from the optimum angle of advance has a small effect for the advance ratios investigated.

RESEARCH, RESEARCH FACILITIES

Wind Tunnels

MODIFICATIONS OF THE BASIC SHOCK TUBE TO IMPROVE ITS PERFORMANCE. A. L. Russo and A. Hertzberg. Cornell Aero. Lab. Rep. AD-1052-A-7 (AFOSR TN 58-716) [AD 162251], Aug., 1958. 43 pp. 11 refs. Study of modifications which would improve the performance of shock tubes in producing higher shock strengths and extend the use of hydrogen in generating strong shock waves in air. These modifications are the double-diaphragm driver with monatomic buffer gases and an area contraction at the diaphragm station. The

results indicate that the use of a shock tube with an area contraction and the proper monatomic buffer gas will permit the generation of strong shock waves, using cold hydrogen as a driver gas, with overall pressure ratios comparable to those required for combustion drivers. It is also shown that, by using a buffer gas with the proper atomic weight, the downstream diaphragm pressure ratio may be controlled to minimize the mass of the downstream diaphragm.

STAGNATION TEMPERATURE CONTROL IN BLOW-DOWN WIND TUNNELS. J. S. Murphy, Duncan Rannie, and G. W. Timson. J. Aero/Space Sci., Nov., 1958, pp. 691-698. 10 refs. Presentation of a design method for limiting the variation of stagnation temperature in a blowdown wind tunnel so that the resultant Reynolds Number variation of the test stream is held within acceptable limits. Temperature control is accomplished by an installation of thermal mass material consisting of thin wall metal tubes or a system of flat and corrugated metal sheets with uniform air passages in the downstream end of the storage reservoir. The method presented has been used to design a thermal mass installation for a 1 x 1 ft. supersonic tunnel. Agreement between calculated and measured air temperature variations is shown to be adequate for design purposes.

SUPERSONIC AERODYNAMIC EXPERIMENTS USING VERY HIGH TEMPERATURE AIR WIND TUNNELS. D. E. Bloxsom, Jr. Jet Propulsion, Sept., 1958, pp. 603-609. 15 refs. Presentation of a series of experiments to demonstrate data which can be obtained from wind tunnels operating at millisec intervals. Supersonic nozzles were constructed and tested by means of jet pressure observations, proving that the isentropic equilibrium flow computations are valid for such high-temperature, high-pressure nozzle expansions. The flow about models can be observed in the self-luminosity of the air. The flow equilibrium studies that have been carried out agree with other experimen tal shock tube results. Drag and heat transfer coefficients are also determined. It is found that throat erosion is a very serious problem in this type of wind tunnel, due to the high temperatures and high heat flux rates. An experimental study is presented which demonstrates that tungsten and carbon throats are to be preferred if wall vaporization is the throat cooling technique.

A HIGH TEMPERATURE STREAM TUBE FOR A SUPERSONIC WIND TUNNEL. Appendix A - ALLOWABLE COMPRESSOR INTAKE TEMPERATURE ESTIMATE. Appendix B - MECHANICAL DESIGN OF THE "HOT CORE" CIRCUIT. Appendix C - TEMPERATURE LOSS IN THE STILLING SECTION. Appendix D - HEATED CORE NOZZLE COORDINATES. Appendix E - TEMPERATURE DATA. Appendix F - PRESSURE AND MACH NUMBER DATA. R. H. Adams. MIT NSL TR 303, May, 1958. 121 pp. 18 refs. Development of a method for obtaining data on aerodynamic heating encountered by aircraft and missiles at supersonic Mach Numbers. A "core" of high-temperature air injected slightly downstream of the throat of a Mach 3.5 nozzle produces a relatively constant Mach Number and temperature region in the 18-in. x 18-in. test section. This region of 900°F. stagnation temperature air was approximately 7-in. x 7-in. and caused no appreciable heating of the tunnel structure. The "hot" test area is approximately the blocking area of the test section. Thus, by heating only one-sixth of the total mass flow of air in the test section, the same aerodynamic heating models may be tested as if the entire mass flow were heated.

ROTATING WING AIRCRAFT, HELICOPTERS

EFFECTS OF COMPRESSIBILITY ON ROTOR HOVERING PERFORMANCE AND SYNTHESIZED BLADE-SECTION CHARACTERISTICS DERIVED FROM MEASURED ROTOR PERFORMANCE OF BLADES HAVING NACA 0015 AIRFOIL TIP SECTIONS. J. P. Shivers and P. J. Carpenter. US, NACA TN 4356, Sept., 1958. 28 pp. Investigation to determine the low tip Mach Number blade maximum mean lift coefficient and high tip Mach Number compressibility effects. Data are presented for blade tip Mach Numbers from 0.27 to 0.81 and corresponding Reynolds Numbers from 1.64×10^6 to 4.78×10^6. Synthesized rotor-blade section-lift and profile-drag-coefficient data derived from experimental data are presented and compared with previously obtained two-dimensional data.

LIFT AND PROFILE-DRAG CHARACTERISTICS OF AN NACA 0012 AIRFOIL SECTION AS DERIVED FROM MEASURED HELICOPTER-ROTOR HOVERING PERFORMANCE. P. J. Carpenter. US, NACA TN 4357, Sept., 1958. 28 pp. 15 refs. Derivation of rotor hovering performance for tip Mach Numbers from 0.28 to 0.70. The principal effect of increasing the blade-tip Mach Number is a large increase in blade drag which occurs at a progressively lower blade mean lift coefficient as the tip Mach Number is increased.

STRESSES IN A BEAM ROTATING IN A CONICAL PATH HELICOPTER BLADE SUBJECT TO UNIFORM LIFT. J. P. O. Silberstein. Australia, ARL S&M Note 242, Apr., 1958. 12 pp. Derivation of an exact solution for the deflection and bending moments of a rotating beam. Two power series solutions are employed to solve the cantilever problem in which boundary conditions at each end have been fitted. An example is evaluated to illustrate to what extent computational troubles are overcome. It is shown that the root bending moment is about the same, whether the blade is clamped at the axis of rotation or at 15% of its length toward the tip.

AN ANALYSIS OF THE LATERAL-DIRECTIONAL STABILITY AND CONTROL OF THE SINGLE ROTOR HELICOPTER. Appendix - CONTROL POSITION IN STEADY ASYMMETRIC FLIGHT. G. F. Langdon and M. C. Neale. Gt. Brit., AAEE Rep. Res/299, May 22, 1958. 32 pp. 11 refs. Solutions of the equations of motion showing that the motion has three constituent parts, two subsidences, and an oscillation. The oscillation is slightly un-

stable at very low speeds, but becomes more and more damped as the speed of the aircraft is increased. It is found that increasing altitude reduces the damping of the oscillatory motion and decreases the rolling effectiveness of the control. Flight measurements of the lateral-directional oscillation agree well with theory except for an overestimation of period at very low speeds. Consideration is given to the effect of varying some design parameters, in particular it is shown that a large increase in roll damping at very low speeds will stabilize the lateral-directional oscillation, and that a decrease in roll damping at high speed can lead to the appearance of a second oscillatory mode which may be unstable.

SPACE TRAVEL

OSNOVNYE PROBLEMY KOSMONAVTIKI. G. V. Petrovich. AN SSSR Vestnik, June, 1958, pp. 28-34. In Russian. Survey of the basic problems of cosmic navigation covering the development of artificial earth satellites; future possibilities -- flight to the Moon, return to Earth of manned vehicles, space stations; and the need for further research in the field of rocket propulsion, information-gathering instruments, and telemetering, guidance, and navigation systems.

SATELLITE ORBITS IN THEORY AND PRACTICE. D. G. King-Hele and R. H. Merson. Brit. Interpl. Soc. J., July-Aug., 1958, pp. 446-470. 20 refs. Analysis of the orbits of Earth satellites, taking into account the effects of the Earth's oblateness and atmosphere. The method of determining the orbit from kinetheodolite and theodolite observations is described, and a comparison is made between theory and observations for Sputnik II. The theoretical predictions of the effect of the Earth's oblateness are confirmed with good accuracy, and the rate of rotation of the orbital plane can be determined from observation. The effects of the atmosphere on the satellite are not in good agreement with theory. In the case of Sputnik II, the discrepancies can probably be ascribed to day-to-day variations in atmospheric density and changes in the mode of rotation of the satellite.

STRUCTURES

Elasticity & Plasticity

ANALYSIS FOR DEEP-DRAWING OF CYLINDRICAL SHELL BASED ON TOTAL STRAIN THEORY AND SOME FORMABILITY TESTS. Shinji Fukui, Hirozo Yuri, and Kiyota Yoshida. Tokyo U., Aero. Res. Inst. Rep. 332, June, 1958. 75 pp. 10 refs. Study, based on the total strain theory combined with octahedral shear theory, in which the actual process is traced as exactly as possible, the local variations of thickness and strain hardening being taken into consideration. The calculated values of strain distributions and punch forces are compared with experimental results on phosphor bronze sheets drawn by a plane die and a conical die, and good agreement is found between them.

Plates

ON AXIALLY SYMMETRICAL PLATES OF VARIABLE THICKNESS. F. Essenburg. U. Mich. Res. Inst. TN 2 (AFOSR TN 58-174) [AD 152205], July, 1958. 6 pp. Study of axially symmetric plates of variable thickness using the basic equations of the Reissner theory for uniform plates, with the thickness treated as a function of the middle plane coordinates. The improvement over the classical theory provided by the developed technique is demonstrated on a simple example.

SMALL DEFLECTION THEORY OF FLAT PLATES USING COMPLEX VARIABLES. II - CLAMPED PLATES. P. D. Jones. Australia, ARL Rep. SM.260, Jan., 1958. 51 pp. 11 refs. Solutions to the fundamental boundary equation for clamped plates under various loading conditions, such as uniform pressure, point loads, and uniform pressure over a region of the plate. The methods of solution are illustrated by numerical examples. Conformal transformation functions which map parallelogram shaped plates onto the unit circle are discussed in detail.

BENDING OF THE CLAMPED EDGED ANISOTROPIC RECTANGULAR PLATES. Appendix - THE LIMITING SUMS OF SOME INFINITE SERIES. Chang Fo-Van. Scientia Sinica, July, 1958, pp. 716-729. Solutions for anisotropic plates by means of a double sine series. Two types of loading are discussed, one is for a uniform load and the other is for a concentrated load acting in the center of the plate. The same method is equally effective if, in addition to the pressure normal to the plate, there are tensile or compressive forces acting in the plane of the plate.

ITERATIVE SOLUTIONS FOR THE NON-LINEAR BENDING OF CIRCULAR PLATES. H. B. Keller and E. L. Reiss. Commun. on Pure & Appl. Math., Aug., 1958, pp. 273-292. AFOSR-sponsored presentation of an iterative method for solving certain boundary value problems that occur in a nonlinear theory of thin elastic shells and plates. The method is developed and its convergence studied for the case of a circular plate subjected to uniform lateral pressure. A variety of edge conditions is considered; these include (a) clamped with zero radial displacement, (b) simply supported with zero radial displacement, (c) simply supported with zero radial membrane stress.

Thermal Stress

THE HEATING OF SLABS WITH ARBITRARY HEAT INPUTS. T. R. Goodman. Allied Res. Assoc. (AFOSR TN 58-524) [AD 158337], May 28, 1958. 17 pp. Derivation of a general approximate relationship between the surface temperature of a heated slab and time by a new method known as the "heat balance integral." The surface heat flux is given as an arbitrary function of surface temperature and time. Includes presentation of few specific examples whose exact solutions are known,

and the error due to the approximations in all cases is shown to be only a few per cent. It is shown how the method may be used when the thermal properties are temperature dependent.

CORRELATION OF THEORETICAL AND PHOTO-THERMOELASTIC RESULTS ON THERMAL STRESSES IN IDEALIZED WING STRUCTURES. Herbert Tramposch and George Gerard. NYU Coll. Eng. Res. Div. TR SM 58-5 (AFOSR TN 58-621) [AD 162150], July, 1958. 39 pp. Application of the photo-thermoelastic method to the experimental evaluation of thermal stress theories. The new technique was correlated with several theories which analyzed the transient thermal stresses in wing structures of high-speed aircraft. Three of these theories were evaluated by duplicating the boundary and initial conditions on plastic models and then by correlating the theories with the observed fringe orders in nondimensional form. The photo-thermoelastic investigations were concluded with the evaluation of a fourth theory, more complicated in its geometrical configuration. The experiments demonstrate the applicability of the photo-thermoelastic method. Due to simplifying assumptions, thermal stresses predicted by the available theories are all higher than the experimental observation.

AN EMPIRICAL METHOD OF DETERMINING THE CRIPPLING STRESS FOR FLANGED FRAMES OF ALCLAD 24 S-T AT ROOM TEMPERATURE AND ELEVATED TEMPERATURE. Gunnar Anevi. SAAB TN 40, Dec. 21, 1957. 24 pp. Results of several tests indicating that: (a) the design rules which apply at room temperature can also be used at elevated temperatures when the properties of the material as they affect the crippling stress are taken into account, and (b) a certain amount of creep has only a moderate adverse effect on the crippling stress. Tentative design data are presented which, in combination with a fairly simple formula or nomogram, can lead to the determination of allowable crippling stress.

THERMODYNAMICS

Combustion

FLAME STABILIZATION IN THE BOUNDARY LAYER OF HEATED PLATES. R. W. Ziemer and A. B. Cambel. (ARS Semi-Annual Meeting, San Francisco, June 10-13, 1957.) Jet Propulsion, Sept., 1958, pp. 592-599. 17 refs. Investigation using a proposed model consisting of a flat plate over which a combustible mixture flows steadily, and a laminar bondary layer is created. A flame propagates upstream through the boundary layer on the plate until the upstream position is reached where the boundary layer is sufficiently thin to quench any further penetration of the flame, and the flame front becomes stabilized at this position. A graphical analysis is proposed and verified by an experimental investigation of propane-air flames. The free stream flow is laminar with a turbulence intensity of 0.4% and the approach mixture velocity is 25 and 50 ft./sec. The maximum Reynolds Number encountered, based on the length of the heated plate, is 122,000.

THE ANALOGUE SOLUTION OF TEMPERATURE DISTRIBUTION AND EXTINCTION IN AN IDEALISED CYLINDRICAL FLAME. D. B. Spalding and M. D. Samain. Imper. Coll. Sci. & Tech. Mech. Eng. Dept. Rep. (AFOSR TN 58-216) [AD 154117], Jan., 1958. 17 pp. Analisis of a simplified model of the "pepper pot" chamber. The main simplification assumes that the flow within the chamber is characterized by a uniform turbulent diffusivity, dependent on the pattern of wall perforation, and that the time-mean volumetric reaction rate depends on time-mean temperature alone. The problem is thus reduced to a one-dimensional nonlinear heat conduction and generation problem with two-point boundary conditions. It has been solved by means of a specially designed resistance-network analog.

Heat Transfer

NATURAL CONVECTION INSIDE A FLAT ROTATING CONTAINER. Simon Ostrach and W. H. Braun. US, NACA TN 4323, Sept., 1958. 27 pp. Analysis indicating that the Froude Number is the parameter that determines the effect of body rotations on internal natural convection flows. Explicit forms of Froude Number are determined for the cases of predominant rotation and axial force. In a heated cylindrical container no significant convective effects are generated by rotations alone. Moreover, rotation tends to inhibit the flow and heat transfer generated by an axial body force in such a configuration. Insertion of radial vanes in the container eliminates the detrimental effects of rotation and improves heat transfer.

VTOL & STOL

POWERED LIFT SYSTEMS. Appendix I - PROPELLER-WING STOVL TRANSPORTS. Appendix II - JET STOVL TRANSPORT. C. H. Zimmerman. (Helicopter Assn. Gt. Brit. Meeting, London, Apr. 11, 1958.) Helicopter Assn. Gt. Brit. J., Aug., 1958, pp. 141-159; Discussion, pp. 159-168. 10 refs. Analysis of powered lift systems which can be used to provide aircraft suitable for operation between city centers and to permit operation of large intercontinental jet transports from fields of moderate size. Two general types of systems are described - propeller-wing combination and jet-wing combination. Four aircraft are described and their performance evaluated. These include three STOVL (short take-off, vertical landing) aircraft for operation from very small airports, and a large, long-range jet transport capable of operating from airports of moderate size. It is concluded that the development and the use of such aircraft will require the solution of several problems including noise, ground interference effects on both propeller-wing and jet-wing powered lift systems, operation and control of a large number of turbojets, and the high cost of small, high thrust-to-weight ratio turbojets.

Détermination de la Distribution des Vitesses Autour des Aubages de Turbine. O. David. *Docaéro*, May, 1958, pp. 49–54. In French. Evaluation of a previously applied method of calculation developed for the determination of velocity distributions over turbine blades.

Head-Flow Characteristics of Axial Flow Helical Inducers. D. A. Rains. *Jet Propulsion*, Aug., 1958, pp. 557, 558. Presentation of several methods used for computing the ideal head-flow characteristics of helical inducers and to compare these results with experimental data.

Method for Computing the Velocity Distribution in a Curved Duct. Sven Hedman. *KTH AERO TN 36*, 1957. 16 pp. Development of the method by using elementary theory; the flow medium is assumed to be incompressible and without internal friction. A comparison between measured and computed values is made and shows satisfactory agreement.

Raschet Krivolineinykh Osesimmetrichnykh Kanalov. G. S. Samoilovich and A. N. Sherstiuk. *AN SSSR Otd. Tekh. Nauk Izv.*, Apr., 1958, pp. 78–81. In Russian. Derivation of an approximate method for the calculation of potential flow of incompressible fluid in curvilinear axisymmetric channels.

Compressible Gas-Flow in Commercial Pipes. Brian Mills and B. N. Cole. *IME Proc.*, No. 19, 1957, pp. 617–632. 15 refs. Investigation of compressible-flow characteristics for commercial grades of piping in which surface-roughness effects may be considerable.

Poteri na Udar v Stupenchatykh Trubakh pri Sverkhzvukovykh Otnosheniiakh Davleniia. L. P. Volkova and M. Ia. Iudelovich. *AN SSSR Otd. Tekh. Nauk Izv.*, Apr., 1958, pp. 67–72. In Russian. Study of the problem of a mixed flow in staggered ducts with supersonic pressure ratio. Includes derivation of analytical formulas for the calculation of full pressure losses. A description of the experimental installation is given, and it is shown that the theoretical results are in good agreement with experiment.

K Teorii Gazovykh Strui. L. N. Sretenskii. *AN SSSR Dokl.*, Apr. 21, 1958, pp. 1,113, 1,114. In Russian. Evaluation of a new set of partial solutions of Chaplygin's equation for the determination of flow functions, and application to the case of a jet of gas exhausting under pressure from a nozzle into free space.

Performance

Osobennosti Letnoi Ekspluatatsii Tiazhelykh Reaktivnykh Samoletov. R. Sakach. *Grazhdanskaia Aviatsiia*, June, 1958, pp. 21–23. In Russian. Evaluation of flight performance of heavy jet aircraft, including flight speed, landing, and structural considerations.

Stability & Control

Investigation of Factors Affecting the Control and Stability of High Speed Aircraft and Missiles; A Review of Work Conducted in This Field. Phrixos Theodorides. *U. Md. Inst. Fluid Dynamics & Appl. Math. TR BN–129 (AFOSR TR 58–52) [AD 154215]*, Apr., 1958. 12 pp. Abstracts of reports on unsteady flow, elasticity of high-speed wings, and shock analysis in nonmonatomic media.

Ob Ustoichivosti Dvizheniia Samoleta s Avtopilotom. S. V. Kalinin. *AN SSSR Otd. Tekh. Nauk Izv.*, Apr., 1958, pp. 114–117. In Russian. Application of previously developed methods for the solution of stability problems to the critical case of motion of an aircraft with automatic pilot.

Some Factors Affecting the Variation of Pitching Moment with Sideslip of Aircraft Configurations. E. C. Polhamus. *U.S., NACA TN 4016*, Aug., 1958. 35 pp. 22 refs.

A Theoretical Analysis of the Effect of Engine Angular Momentum on Longitudinal and Directional Stability in Steady Rolling Maneuvers. O. B. Gates, Jr., and C. H. Woodling. *U.S., NACA TN 4249*, Apr., 1958. 20 pp.

Determination of Longitudinal Stability and Control Characteristics from Free-Flight Model Tests with Results at Transonic Speeds for Three Airplane Configurations. C. L. Gillis and J. L. Mitchell. *U.S., NACA Rep. 1337*, 1957. 28 pp. 16 refs. Supt. of Doc., Wash., $0.30.

Wings & Airfoils

Some Measurements of Aerodynamic Forces and Moments at Subsonic Speeds on a Rectangular Wing of Aspect Ratio 2 Oscillating About the Midchord. Appendix A—**Correction of Root Reaction for Inertia and Aeroelastic Effects to Determine the Total Aerodynamic Load.** Appendix B—**Determination of the Aerodynamic Damping-Moment Coefficient.** Appendix C—**Some Experimental Evidence of Wind-Tunnel-Wall Effects on an Oscillating Wing.** Edward Widmayer, Jr., S. A. Clevenson, and S. A. Leadbetter. *U.S., NACA TN 4240*, May, 1958. 45 pp. 14 refs.

Détermination des Coefficients Aérodynamiques Instationnaires sur une Aile Delta, de Mach 0 à Mach = 1,35. R. Dát and R. Destuynder. *La Recherche Aéronautique*, May-June, 1958, pp. 57, 58. In French. Determination of nonstationary aerodynamic coefficients for a delta wing at Mach Numbers from 0 to 1.35.

Method for Calculating the Aerodynamic Loading on an Oscillating Finite Wing in Subsonic and Sonic Flow. Appendix A—**Numerical Example of the Lifting-Surface Method for a Rectangular Wing.** Appendix B—**Treatment of Certain Integrals Which Contain Singularities That Arise in the Chordwide Integration.** Appendix C—**Calculation of Moment on Delta Wing.** Appendix D—**Description of a Multiple-Line-Method.** H. L. Runyan and D. S. Woolston. *U.S., NACA Rep. 1322*, 1957. 30 pp. 37 refs. Supt. of Doc., Wash., $0.30.

Investigation of Downwash, Sidewash and Mach Number Distribution Behind a Rectangular Wing at a Mach Number of 2.41. Appendix A—**Calibration of Mirror Normals and Method of Reducing Optical Data to Downwash and Sidewash.** Appendix B—**Theoretical Evaluation of Downwash and Sidewash.** David Adamson and W. B. Boatright. *U.S., NACA Rep. 1340*, 1957. 57 pp. 12 refs. Supt. of Doc., Wash., $0.55.

O Sverkhzvukovykh Profiliakh, Imeiushchikh Minimal'noe Soprotivlenie. Iu. D. Shmyglevskii. *Prikl. Mat. i Mekh.*, Mar.-Apr., 1958, pp. 269–273. In Russian. Study of the problem covering the determination of a supersonic profile with minimum drag.

Minimum Wave Drag for Arbitrary Arrangements of Wings and Bodies. R. T. Jones. *U.S., NACA Rep. 1335*, 1957. 6 pp. 14 refs. Supt. of Doc., Wash., $0.15. Analysis to determine the minimum possible value of the wave resistance obtainable by any disposition of the elements of an aircraft within a definitely prescribed region.

Methods for Determining the Wave Drag of Non-Lifting Wing-Body Combinations. L. M. Sheppard. *Gt. Brit., ARC R&M 3077* (Apr., 1957) 1958. 28 pp. 37 refs. BIS, New York, $1.80.

Experimental Measurements of the Effects of Airplane Motions on Wing and Tail Angles of Attack of a Swept-Wing Bomber in Rough Air. J. N. Engel. *U.S., NACA TN 4307*, Aug., 1958. 25 pp. 11 refs.

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241]. Dec., 1957. 38 pp. Study of the work by Haskind and Falkovich to clarify their numerical solutions.

Aeroelasticity

A Search for Definitions and Criteria Relating to Non-Oscillatory Divergence in Near Steady Flight Conditions. E. Billion. (*NATO AGARD Flight Test Wind Tunnel Panels, Brussels, Aug. 27–31, 1956.*) *NATO AGARD Rep. 72T*, Aug., 1956. 12 pp.

Un Avion Peut-il Avoir deux Fréquences Propres Egales? H. Gauzy and Y. Pironneau. *La Recherche Aéronautique*, May-June, 1958, pp. 43–48. In French. Theoretical study of the natural frequencies of a vibrating system. Includes comparison with experimental results, as well as a description of the application to aircraft ground vibration tests.

O Subgarmonicheskikh Kolebaniiakh Sterzhnei s Nelineinoi Inertsionnost'iu. V. A. Ivovich. *AN SSSR Dokl.*, Mar. 11, 1958, pp. 237–240. In Russian. Derivation of solutions for the problem of subharmonic oscillations of rods with nonlinear inertia.

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A Random Distribution of Gusts Corresponding to a Measured Frequency of Vertical Gusts. M. Fine. *Aero. Quart.*, Aug., 1958, pp. 251–257. Description of a method to estimate the frequency of gust components in the plane of a propeller from measurements of vertical gust components, which are those generally recorded.

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Aeronautics, General

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Airplanes

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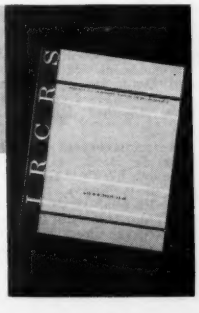

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XUM

"ECLIPSE" a recent painting by Simpson-Middleman, gifted artistic interpreters of the physical sciences. About this new expression they write: "'Eclipse was painted as a result of watching an actual eclipse of the sun. We were particularly struck with the curious light that was both dim and glowing and the unusual pattern of the shadows on the leaves of the trees around us. We had never seen anything like it before." Painting courtesy of John Heller Gallery, Inc.

Space projects at Boeing

Engineers and scientists at Boeing are at work on advanced projects that include a space weapon system based on a manned orbital vehicle capable of re-entry into the atmosphere and normal landing. This major contract-supported program is a result of recognition of Boeing's space-age orientation, its tremendous technical and research capability and its extensive weapon system management experience.

Among other space efforts at Boeing is a study for an unmanned Martian reconnaissance vehicle powered by an ion accelerator. The vehicle would escape at low continuous thrust to an Earth-Mars transfer orbit, then descend to a Martian orbit where it would optically observe the surface of the planet. The controllable-thrust capabilities of ion propulsion would permit correction of flight-path deviations from a "memory" electronically pre-programmed into the vehicle. Fine corrections would be made possible by an optical star-tracking system.

These and other rapidly expanding space flight programs have created exceptional career opportunities at Boeing for scientists and engineers of all categories. For complete details, drop a note now to Mr. Stanley M. Little, Department A-81, Boeing Airplane Company, Seattle 24, Washington.

BOEING

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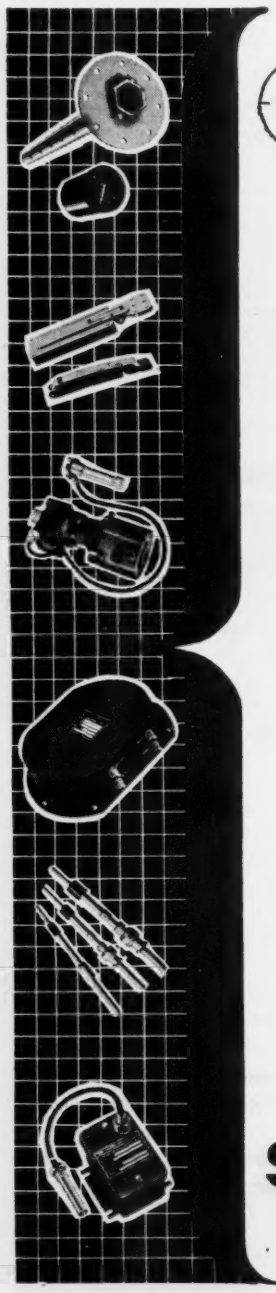

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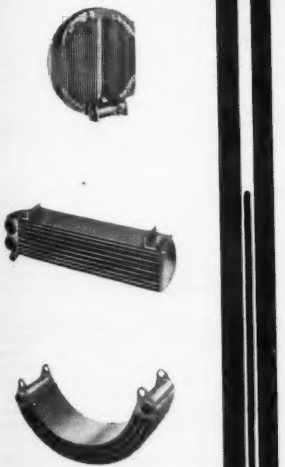

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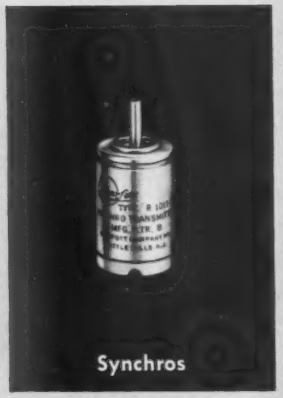

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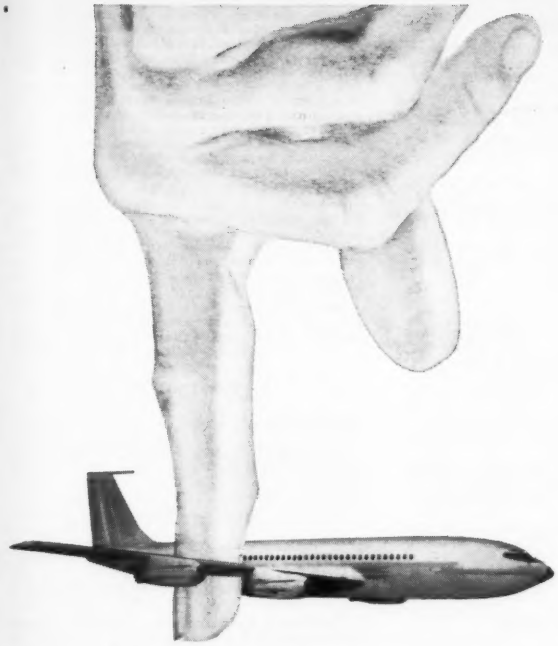

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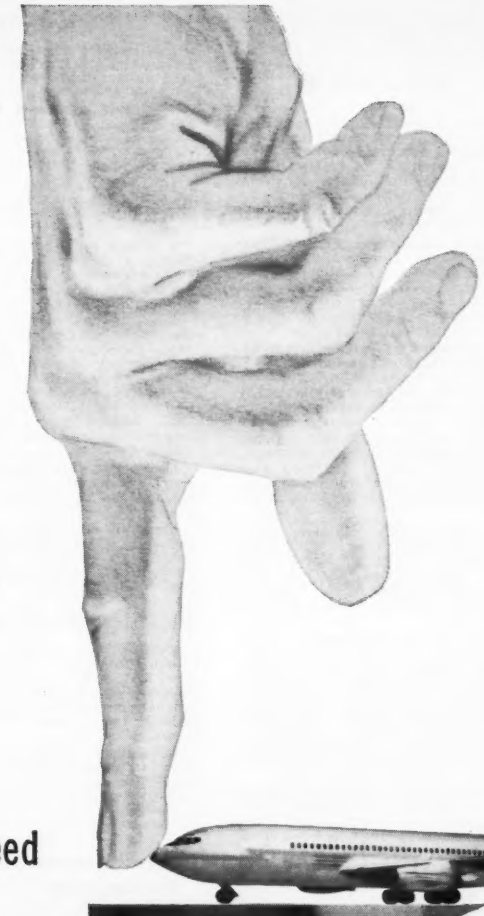

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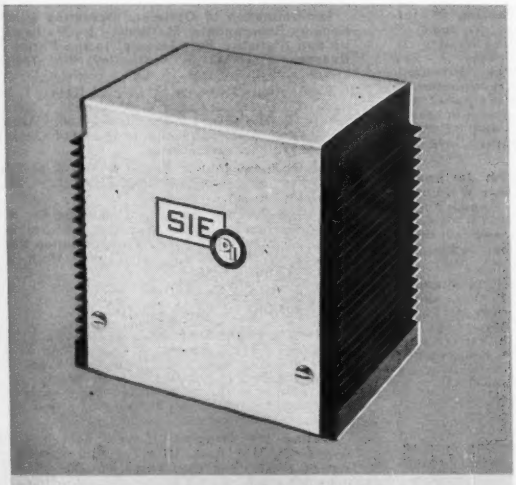

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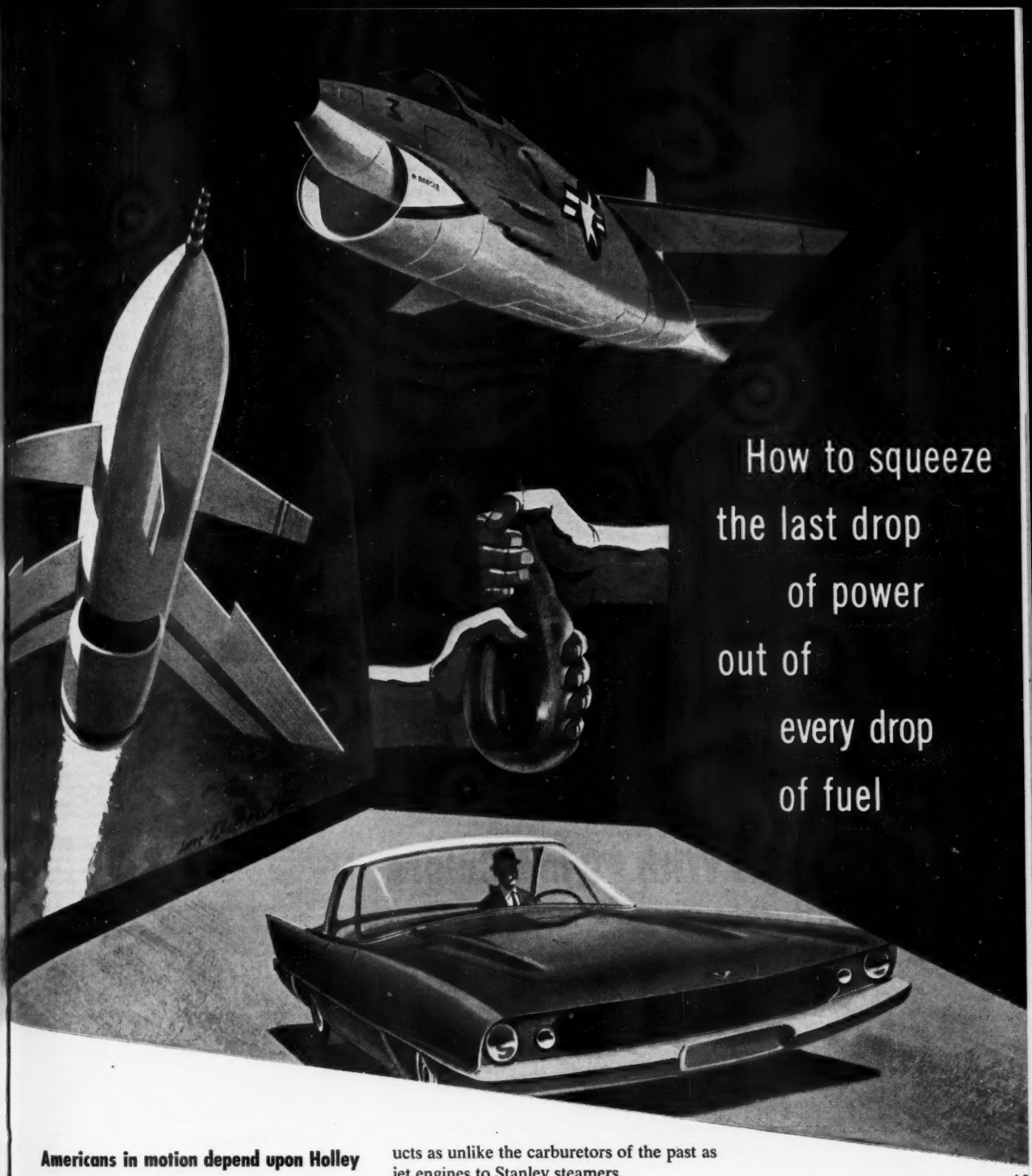

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Los Angeles, July 8–11, 1958, Preprint 842. Members, $0.35; nonmembers, $0.75. 5 pp. Discussion of the manner in which observational data can be incorporated in interplanetary orbiting missions. Specific examples of the navigational accuracy required in take-off speed and by employment of "braking ellipses" at landing are presented.

Operation Manhigh II. O. C. Winzen and D. P. Parks. *Jet Propulsion*, Aug., 1958, pp. 523–532. 10 refs. Description covering the balloon and capsule system, as well as the flight operation.

Observations Made During Manhigh II Flight. D. G. Simons. *Jet Propulsion*, Aug., 1958, pp. 521, 522. Discussion of studies made during a manned ascent to the 100,000 ft. region. Observations included evaluation of the balloon-capsule system performance and meteorological, astronomical, and medical studies.

Satellite Instrumentation Gathers Information. *Ind. Sci. & Eng.*, Apr., 1958, pp. 10–12, 14. Brief discussion including information on satellite signal reports, orbital position, and protection of instruments.

Microlock: A Minumum Weight Radio Instrumentation System for a Satellite. H. L. Richter, Jr., W. S. Sampson, and Robertson Stevens. *Jet Propulsion*, Aug., 1958, pp. 532–540. Discussion covering the design, construction, and laboratory testing of a satellite tracking system. The tracking mechanism employs a low-power, light-weight flight transmitter in conjunction with a receiving system of advanced design.

Satellite "Eyes" to View Earth Weather Conditions. William Strouse. *Missiles & Rockets*, June, 1958, pp. 72–75. Discussion of the use of satellite weather eyes. The stratoscope telescope and the Vanguard weather eye are described.

Samaia Krupnaia v Mire Kosmicheskaia Laboratoriia. *Grazhdanskaia Aviatsiia*, June, 1958, pp. 6, 7. In Russian. Description of the third Soviet artificial satellite in terms of astrophysical data obtained.

Erdsatellit "Sputnik" III. W. Michely. *Luftfahrttechnik*, June 15, 1958, pp. 177, 178. In German. Brief survey of available data on the Soviet satellite Sputnik III.

Sputnik as a Tool for Securing Geodetic Information. Louis Gold. *Franklin Inst. J.*, Aug., 1958, pp. 103–107. Description of the way in which Sputnik tracking data, including perigee and apogee, period and orbital velocity, may be used to deduce such important geodetic facts as the mass and mean radius of the Earth without any knowledge of the launching conditions.

Ergebnisse von Temperaturmessungen mit "Explorer" I. W. Michely. *Luftfahrttechnik*, June 15, 1958, p. 178. In German. Brief presentation of results on temperature measurements obtained from the Explorer I satellite.

Il Razzo Lunare. Glauco Partel. *Riv. Aero.*, June, 1958, pp. 819–830. In Italian. Discussion of the basic problems of flight to the Moon, including the design and propulsion of a vehicle, as well as presentation of pertinent data.

Structures

Some Stress Analysis Problems of Current High-Speed Fighter Aircraft and Their Educational Implications. J. F. Yardley. *J. Eng. Educ.*, Apr., 1958, pp. 631–639. Discussion including problems in internal loads, structural efficiency, fatigue, thermal stresses, and stiffness requirements.

De Quelques Réalisations Françaises dans le Domaine des Structures Nouvelles. B. Dorléac. (*NATO AGARD 6th Structures & Materials Panel, Paris, Nov. 4–8, 1957.*) *Docatro*, May, 1958, pp. 3–14. In French. Survey of French development with new methods of construction, including advantages and limitations of integral and sandwich construction, and an illustrative application to the Trident SO-9050 wing.

Bars & Rods

Mestnye Napriazheniia pri Kruchenii Kruglogo Prizmaticheskogo Brusa s Ellipticheskim Nesoosnym Otverstviem. Iu. A. Amenzade. *AN SSSR Dokl.*, Apr. 21, 1958, pp. 1,118–1,121. In Russian. Determination of local stresses in a twisted circular prismatic rod with an elliptical noncoaxial hole.

Ustoichivost' Ravnovesiia Sterzhnei s Tochki Zreniia Matematicheskoi Teorii Uprugosti. K. F. Voitsekhovskaia. *AN SSSR Dokl.*, Apr. 11, 1958, pp. 903–906. In Russian. Application of the mathematical theory of elasticity to the spacial problem of compression stability in elastic circular rods.

Beams & Columns

The Behaviour of Webplates of Plate Girders Subjected to Pure Bending. K. C. Rockey and F. Jenkins. (*Struc. Engr.*, May, 1957.) *ADA Res. Rep. 33*, Aug., 1957. 17 pp. 23 refs. Reprint. Test results for elastic and inelastic buckling of web plates.

Creep Deflexion and Stress Distribution in a Beam. W. J. Goodey. *Aircraft Eng.*, June, 1958, pp. 170–172. Analysis of the stress distribution in a beam subjected to a constant bending moment.

Cylinders & Shells

K Obshchei Teorii Anizotropnykh Obolochek. S. A. Ambartsumian. *Prikl. Mat. i Mekh.*, Mar.-Apr., 1958, pp. 226–237. 13 refs. In Russian. Derivation of the general theory of anisotropic shells and analysis of several illustrative cases.

O Variatsionnom Printsipe Kompleksnoi Teorii Obolochek. K. F. Chernykh. *Prikl. Mat. i Mekh.*, Mar.-Apr., 1958, pp. 238–244. In Russian. Evaluation of the variational principle in the complex theory of shells.

Ustoichivost' Uprugo-Plasticheskikh Neodnorodnykh Obolochek. E. I. Grigoliuk. *AN SSSR Dokl.*, Apr. 1, 1958, pp. 663–666. In Russian. Study of the stability of elasto-plastic inhomogeneous shells, with derivation of a formula for determining the critical forces of the local stability loss under combined loading.

On Simplified Fuselage-Structure Stress Distributions. W. R. Jensen. *J. Aero/Space Sci.*, Oct., 1958, pp. 656, 657. Description of a new technique to obtain simplified accurate structure stress distribution. The results are compared graphically with other procedures.

Elasticity & Plasticity

Solution of the Plane Problem of Elasticity in a System of Cartesian Coordinates, Mass Forces Being Taken Into Consideration. Franciszek Szelągowski. *Arch. Mech. Stosowanej*, No. 1, 1958, pp. 99–105.

Difraktsiia Ploskoi Uprugoi Volny Otnositel'no Ugla. V. A. Sveklo and V. A. Siukiiainen. *AN SSSR Dokl.*, Apr. 21, 1958, pp. 1,122, 1,123. In Russian. Study covering the problem of diffraction of a plane elastic wave relative to an angle.

Ploskaia Deformatsiia Neszhimaemogo Materiala. L. A. Tolokonnikov. *AN SSSR Dokl.*, Apr. 21, 1958, pp. 1,124–1,126. In Russian. Study of the problem of plane deformation of incompressible materials and introduction of simplifying assumptions.

The Three-Dimensional Elastic Problem for a Wedge with Given Boundary Displacements. Ya. S. Uflland. (*AN SSSR Dokl.*, No. 6, 1955, pp. 1,177–1,179.) *Australia, ARL Trans. 15*, June, 1958. 5 pp. Translation.

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Aerodynamics, A Series of Papers Revised and Reprinted from 'Research' Vol. 10, 1957. London, Butterworths Scientific Publications; New York, Interscience Publishers, Inc., 1957. 47 pp., illus., diagrs. $2.50.

Contents: Aerodynamics: Theory and Practice, T. Nonweiler. Wings and Bodies in Low Speed Flow, J. L. Stollery. Aircraft Performance, Stability and Control, A. W. Babister. High Speed Flight, J. Black. The Aerodynamic Laboratory, J. Black. Current Aerodynamic Problems, W. J. Rainbird.

AERONAUTICS, GENERAL

Proceedings of the Seventh AGARD General Assembly, November 25–26, 1957. (The Washington AGARD Conference, November 18–26, 1957.) Paris, NATO AGARD, 1957; Distributed in U.S. by NACA, Washington. 101 pp., illus., diagrs.

Contents: Growth of Air Power in the United States, N. F. Twining. Towards Higher Altitude: Round Table Discussion, Hugh L. Dryden, Chairman. Physics of the Stratosphere and Ionosphere, W. Dieminger. Aerodynamics of Low Density Media, G. N. Patterson. Propulsion at High Altitudes, M. Florio. Human Parameters of Space Flight, P. A. Campbell. High Altitude Flight Testing, I. C. Kincheloe, Jr., and H. M. Drake. Reports of Panel Chairmen: Aeromedical Panel, E. Evrard. Combustion and Propulsion Panel, J. Ducarme. Flight Test Techniques and Instrumentation, A. J. Marx. Structures and Materials, L. Broglio. Wind Tunnel and Model Testing, I. A. Abbott. Documentation Committee, R. A. Kennedy. Report on AGARD Secretariat, F. L. Wattendorf. List of Panel Papers.

1958 First Award Papers; IAS Student Branch Paper Competition. New York, Minta Martin Aeronautical Student Fund, Institute of the Aeronautical Sciences, Inc., 1958. 127 pp., illus., diagrs., tables.

The papers that make up this fifth annual edition were presented at seven IAS regional conferences held in the spring of this year. Each paper was judged a first-place winner by a board of judges and was published by the IAS as a means of providing additional encouragement and incentive to the engineering student and assisting him in defining his own professional goals.

Contents: Effect of Air Temperature on Vortex Shedding Behind Cylinders, William D. Clifford. The Laminar Boundary Layer Flow on an Axis Symmetric Body with Transverse Curvature Effect, Joseph Tsu Chieh Liu. Flutter of Two Dimensional Panels in Transonic Regime, Malcolm H. Lock. An Experimental Investigation of Internal Compression Intake Nozzles with Perforated Walls, George Michos. An Investigation of Barium as an Ionic Fuel, Robert M. Nerem. Aerodynamic Characteristics of a Hemisphere in Newtonian Flow, Edgar Brian Pritchard. An Escape Trajectory for a Vehicle in the Earth-Moon Gravity Field, Lester W. Roane. A Potential Flow Study of the Lift on Slender Bodies of Revolution, A. Richard Seebass. Longitudinal Stability Derivatives of Missile Shaped Bodies at Hypersonic Speeds, Robert H. Tolson. An Experimental Verification of Static Stability Predicted by Nonlinear Elastic Beam-Column Theory, Thomas L. Vincent. Medical Aspects of Human Flight, John B. Whitlow, Jr.

COMPUTERS

Joint New York University, International Business Machines Corporation Symposium on Digital Computing in the Aircraft Industry, January 31–February 1, 1957, New York University College of Engineering, Gould Student Center, University Heights Campus. Co-Sponsored by Institute of the Aeronautical Sciences and Society for Industrial and Applied Mathematics. IBM-NYU Symposium, 401 W. 205th St., New York 34, N.Y., 1957. 399 pp., illus., diagrs. $8.00.

Contents: Transient Water Loads, Solis James. Use of Digital Computing for Aerodynamic Performance Studies, J. J. Moses and W. H. Weideman. Gust Spectra from Aircraft Measurements, U. Oscar Lappi. A Comparison of Fourier Analysis and Auto-Correlation Techniques for Harmonic Analysis, Cecilia Y. Fleck. Application of Dynamic Programming to the Airplane Minimum Time to Climb Problem, T. F. Cartaino and S. E. Dreyfus. Transient Thermal Analysis, Robert K. Prince and Thomas A. Sedgwick. Tailor-Made Computing System, Mandalay Grems. Operation of a Complete Computing Center for an Aircraft Company, Lee A. Ohlinger. Application of a Digital Data Handling System to Flight Test Organization, Charles E. Pettingall. Automatic Wind Tunnel Data Reduction, David Feign, R. MacArthur, and V. Widler. The New Look in Engineering, Daniel O. Dommasch. Dynamic Considerations in Aircraft, Autopilot and Guidance Systems, R. J. Kochenburger. An Experiment in Conformal Mapping, T. J. Rivlin and C. L. Eisen. Analysis of Landing Gear Systems, James L. Edman. Survey of Multi-Group Reactor Calculations, Ward C. Sangren. Generalized Seat Ejection System Study, George B. Fallon. Digital Systems Analysis, Everett R. Welmers. Computation of Missile Trajectories in Three Dimensions, Clagett Bowie. Recursion Formulas for Generating Sampled Filtered Noise on a Digital Computer, Marvin Blum. Numerical Solutions or Ordinary Differential Equations, John Horner and Mark Robinson. Eigenvalues in Modern Industry: (1) Survey of Physical Origin and Mathematical Formulation, J. A. Brooks and E. Levin. (2) Computing Techniques for Matrices, Werner L. Frank and Ivin Tarnove. (3) Problems Involving Differential Operators, S. D. Conte and David Young.

ELECTRONICS

Principles of Electronic Instruments. Gordon R. Partridge. Englewood Cliffs, N.J., Prentice-Hall, Inc., 1958. 393 pp., diagrs., tables. $11.

Specifically designed to show how electronic instruments function and why each is used, this book explains the principles and practices of electronic instrumentation in a way that aids the reader in designing his own special-purpose instruments. The book is based on the principle that almost anything can be measured with an electronic instrument, provided the unknown quantity can be converted into an electrical signal. Within this framework, the author, who is a Senior Engineer in the Communications Department, Raytheon Manufacturing Co., discusses such topics as "Why Electronic Instruments," "The Significance of Voltage Measurements," "AC Electronic Voltmeters," "Frequency Measuring Instruments," and "Digital Display."

ENGINEERING

Engineering Systems Analysis. Robert L. Sutherland. Reading, Mass., Addison-Wesley Publishing Co., Inc., 1958. 223 pp., diagrs. $7.50.

Written for students of engineering on the advanced undergraduate level, this text is designed to point up the similarity between topics in different fields of engineering by means of analogies which exist in the mathematical description of the problems involved and in the character and form of the solutions to the problems. The aim of the book is to show the engineer that certain methods of analysis and solution, such as dimensional analysis and high-speed computing machines, which he often considers to be specialized tools for his own branch, are in reality broad and powerful generalized tools which are extremely valuable when unusual problems are encountered. The author is Associate Professor of Mechanical Engineering, State University of Iowa.

Contents: (1) Analogs and Engineering Analogies. (2) Mechanical Vibrations. (3) Oscillations in Electrical Networks. (4) Dynamical Systems and their Characteristics. (5) Methods of Solution for Analogous Systems and Mixed Systems. (6) Dimensional Analysis and Applications. (7) Principles of Feedback and Control. (8) Analog and Digital Computing Machines. Answers to Problems. Index.

FLUID MECHANICS

Fluid Dynamics and Heat Transfer. James G. Knudsen and Donald L. Katz. New York, McGraw-Hill Book Co., Inc. 576 pp., illus., diagrs., tables. $12.50.

In this presentation of the fundamentals of fluid dynamics which are basic to an understanding of convection heat transfer, the material is developed from the application of first principles in fluid dynamics and heat transfer through the practical formulations used in design procedures. The book brings together both theoretical aspects and quantitative data on heat transfer and fluid dynamics. Basic principles of various types of fluid flow are presented in the first eleven chapters, which serve as a foundation for the discussion of several aspects of forced-convection heat transfer in the concluding chapters.

The authors are, respectively, Professor of Chemical Engineering, Oregon State College, and Professor of Chemical Engineering and Chairman, Department of Chemical and Metallurgical Engineering, University of Michigan.

GRAPHICS

Introductory Graphics. J. Norman Arnold, and others. New York, McGraw-Hill Book Co., Inc., 1958. 543 pp., diagrs. $7.75.

Nine hundred illustrations and 33 pages of tables are used in this engineering drawing book which emphasizes graphical solutions to engineering and mathematical problems. The text is designed to help the beginning student of engineering in the graphic representation of objects, data, and physical phenomena, as well as the solution of space and graphical analog problems. Some special topics incude chapters on graphical calculus, empirical equations, and an elementary treatment of map projection.

The author is Professor of Engineering Graphics, Purdue University.

HELICOPTERS

The Helicopter. Jacob Shapiro. London, New York, The Macmillan Co., 1958. 269 pp., illus., diagrs. $4.50.

This book for the general reader includes an account of its history, a description of a typical helicopter, its design and operating efficiences, principles of vertical flight, physics of the rotating wing, various uses of the helicopter in war and peace, and its potential in the future.

The author is an active helicopter engineer and designer in Great Britain.

ICE FORMATION & PREVENTION

Icing Problems and Recommended Solutions. Presented to the Flight Test Techniques and Instrumentation Panel of AGARD, July, 1956; Amendments Included up to November, 1957. Edmond A. Brun, General Editor. (AGARDograph No. 16.) Paris, NATO AGARD, 1957; Distributed in U.S. by NACA, Washington. 264 pp., illus., diagrs., tables.

Contents: (1) General Survey, E. A. Brun. (2) Icing Conditions to be Considered in the Design of Protection Systems, D. Fraser and K. G. Pettit. (3) The Measurement of Icing Conditions, D. G. A. Rendel and F. J. Bigg. (4) Icing Wind Tunnel Tests, R. B. Morrison, J. A. Nicholls, R. E. Cullen, and H. E. Stubbs. (5) Flight Tests in Simulated Icing Conditions, G. C. Abel and J. K. Thompson. (6) Icing Flight Test Concepts in the U.S.A., James K. Thompson.

MATERIALS

Fluorocarbons. Merritt Allen Rudner. New York, Reinhold Publishing Corp., 1958. 238 pp., illus., diagrs., tables. $5.75.

This monograph presents the history, properties, chemistry, method of manufacture, and applications of the fluorocarbon materials. It also gives their capabilities and limitations as compared with other plastics and describes their electrical, mechanical, and chemical applications.

The author is President, Enflo Corp.

Cellulosics. Walter D. Paist. New York, Reinhold Publishing Corp., 1958. 270 pp., illus., diagrs., tables. $5.75.

This concise survey of the field of cellulosics and their applications includes the chemistry, properties, and fabrication methods of the materials with extensive examples of their applications—fibers, films, molding powders, protective coatings, adhesives, thickening agents, etc. The author, who is with the Plastic Division, Celanese Corp. of America, concludes the work with an appraisal of the industrial future of the cellulosics.

Vinyl Resins. W. Mayo Smith. New York, Reinhold Publishing Corp., 1958. 285 pp., illus., diagrs., tables. $5.75.

The author, Director of Research and Development, Escambia Chemical Corp. Research Center, has put the emphasis upon the applications of the

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MATHEMATICS

Functions of Real Variables. William Fogg Osgood. (Reprint of 1935 Edition.) New York, Chelsea Publishing Co., 1958. 262 pp. $4.95.

Elementary Number Theory. Edmund Landau. Translated from the German by Jacob E. Goodman; With Exercises by Paul T. Bateman and Eugene E. Kohlbecker. (Reprint of the 1927 Edition.) New York, Chelsea Publishing Co., 1957. 256 pp. $4.95.

Matrix Theory for Physicists. J. Heading. London, New York, Longmans, Green and Co., 1958. 242 pp. $6.50.

The approach adopted throughout this book is to treat matrix theory as a tool rather than a branch of abstract algebra. After devoting the first two chapters to the basic mathematical theory, the author then applies the theory to the subjects of three-dimensional geometry, dynamics, electromagnetic theory, special theory of relativity, and quantum mechanics.

The author is Senior Lecturer in Mathematics, West Ham College of Technology.

NUCLEAR ENERGY

Nuclear Rocket Propulsion. R. W. Bussard and R. D. DeLauer. New York, McGraw-Hill Book Co., Inc., 1958. 370 pp., illus., diagrs., tables. $10.

In this volume, which introduces the reader to the new McGraw-Hill Series in Missiles and Space Technology, the authors present a comprehensive picture of a pioneer field of nuclear power application which is expected to supplant conventional chemical propulsion as a thrust-producing device, at least for vehicle missions involving heavy payloads and long ranges such as for the establishment and continuing supply of large earth satellites. By joining nuclear reactor technology to the characteristics of rocket-motor gas dynamics and the inherent features of ballistic-rocket-vehicle flight, they afford the physicist, the engineer, and the designer an insight into the requirements and future possibilities of advanced, high-performance nuclear propulsion systems. No attempt is made to include chemical rockets per se since the literature in this field is more readily available.

Contents: (1) Introduction. (2) Basic Rocket Performance. (3) System Analysis. (4) Heat Transfer and Fluid Flow. (5) Materials. (6) Nucleonics. (7) System Control. (8) Testing. (9) Advanced and Exotic Systems. Appendix.

Application of Atomic Engines in Aviation. G. N. Nesterenko, A. I. Sobolev, and Iu. N. Sushkov. (Translation of **Primenseniie atomnykh dvigatelei v aviatsii.** Moscow, Military Press of the Ministry of Defense of the U.S.S.R., 1957.) (PB-131908 T.) Washington, Office of Technical Services, 1958. 184 pp., diagrs. $3.00.

Primenenie Atomnykh Dvigateley v Aviatsii (Application of Atomic Engines in Aviation). G. N. Nesterenko, A. I. Sobolev, and Iu. N. Sushkov. (Nauchno-Populiarnaia Biblioteka.) Moscow, Voennoe Izdatel'stvo Ministerstva Oborony Soiuza SSR, 1957. 168 pp., diagrs.

We have here both the original and a translation of a pamphlet which aims to systematize the scattered data in world literature (with emphasis on Russian sources) dealing with the utilization of atomic power plants in aviation and rocket engineering. The information has been presented to be read and understood by a wide range of readers and covers the following areas:

(1) Perspectives for the use of atomic energy in aviation, which deals with the use of chemical, petroleum, and nuclear fuels.

(2) Nuclear reactors for aircraft power plants, which gives the design and specifications for different types of nuclear reactors and the difficulties in developing them for use in aircraft.

(3) Possible diagrams of aircraft atomic power plants, which gives details of the following engines: atomic rocket, ram-jet atomic, atomic turbojet atomic turboprop, atomic turbojet with motor-driven compressor, and combined nuclear-chemical fueled engine.

(4) Aircraft with atomic engines, which discusses the different radiation rays to be dealt with, and the design and handling features of aircraft of this type.

(5) Atomic energy and interplanetary flight, which deals with cosmic velocities and atomic space rockets.

OPERATIONS RESEARCH

A Comprehensive Bibliography on Operations Research, Through 1956, with Supplement for 1957. Operations Research Group, Engineering Administration Dept., Case Institute of Technology. Beverly Bond, Harish Merchant, and Arthur J. Yaspan. With Financial Support from Case Institute of Technology and Operations Research Society of America. (Operations Research Society of America, Publications in Operations Research, No. 4.) New York, John Wiley & Sons, Inc., 1958. 188 pp., $6.50.

This bibliography contains approximately 3,000 titles of books, articles, reports, and proceed-

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ings published through December, 1957, which deal with some aspect of operations research. The list includes all articles published in the *Journal of the Operations Research Society of America*, the *Operations Research Quarterly*, *Management Science*, and the *Naval Research Logistics Quarterly*. The ordering of entries in the text is, in general, alphabetical by author. For ease in cross-referencing, each entry has been assigned a numerical designation. While there are no annotations as such, each entry is also accompanied by a ten-digit classification number (IBM entries, explained in the foreword) in which is encoded the following information: general classification of the article, type of organization involved, function or type of activity involved, techniques used or described, aspects or research discussed, and aspects of practice discussed. One section of the book contains about 40 special bibliographies where articles with the same subject are listed by numerical description.

PHYSICS

Solid State Physics; Advances in Research and Applications, Vol. 6. Edited by Frederick Seitz and David Turnbull. New York, Academic Press, Inc., 1958. 429 pp., diagrs., tables. $12.

The introduction to this volume contains a listing of the contents of the previous five volumes and a bibliography (46 items) of articles planned for future volumes.

Contents: Compression of Solids by Strong Shock Waves, M. H. Rice, R. G. McQueen, and J. M. Walsh. Changes of State of Simple Solid and Liquid Metals, G. Borelius. Electroluminescence, W. W. Piper and F. E. Williams. Macroscopic Symmetry and Properties of Crystals, Charles S. Smith. Secondary Electron Emission, A. J. Dekker. Optical Properties of Metals, M. Parker Givens. Theory of the Optical Properties of Imperfections in Nonmetals, D. L. Dexter.

PRODUCTION

Titanium Welding Techniques. (Titanium Engineering Bulletin No. 6.) New York, Titanium Metals Corp. of America, 1958. 31 pp., illus., diagrs., tables.

This bulletin presents a comprehensive evaluation of successful welding methods used in the titanium industry and covers the following topics: fusion-welding equipment and procedures, resistance-welding equipment and procedures, a study of typical weldments, methods for evaluating weld quality, welded joint designs, guaranteed mechanical properties of weldable grades of titanium, and recommended settings for open-air machine welding.

Standard Aircraft Handbook. Stuart Leavell and Stanley Bungay. 2nd Ed. Los Angeles, Aero Publishers, Inc., 1958. 160 pp., illus., diagrs., tables. $2.75.

Twenty-eight major aircraft factories and material suppliers have assisted in the preparation of this pocket-size reference and training manual for aircraft workers and mechanics in factories and maintenance companies. The subjects dealt with are riveting, bolts and fasteners, tools and their proper use, assembly and installation methods, materials and fabrication, blueprint reading, lofting and templates, and the most common AN standard parts.

SPACE MEDICINE

Physical and Physiological Data for Bioastronautics. Ellis R. Taylor. Randolph AFB, Texas, USAF School of Aviation Medicine, March 18, 1958. 149 pp., illus., diagrs., tables. Loose-leaf.

The purpose of this handbook is to gather together, under one cover, useful data pertinent to the development of space flight: the physical environments of various portions of space and the needs and limitations of the human organism under space flight conditions. The data presented here have been taken from recent books, Air Force manuals, and technical reports, industrial literature, and scientific journals; they include physical and astrophysical data concerning the earth, its atmosphere, useful physical properties of matter and energy, and physiological data.

The editor, Capt. Ellis R. Taylor, USAF (MC), is Resident, Aviation Medicine, USAF School of Aviation Medicine.

Bibliography of Space Medicine. U.S. Dept. of Health, Education, and Welfare; Public Health Service; and the National Library of Medicine, Reference Division. (Public Health Service Publication No. 617; Public Health Service Bibliography Series No. 21.) Washington, 1958. 49 pp.

The 381 references for this bibliography have been selected from indexes and catalogs of the National Library of Medicine and from the principal aviation, aviation medicine, and astronautical publications. They are arranged in broad subject classes, in inverse chronological order alphabetically by author within the years, with brief annotations occasionally included. There is an index of authors.

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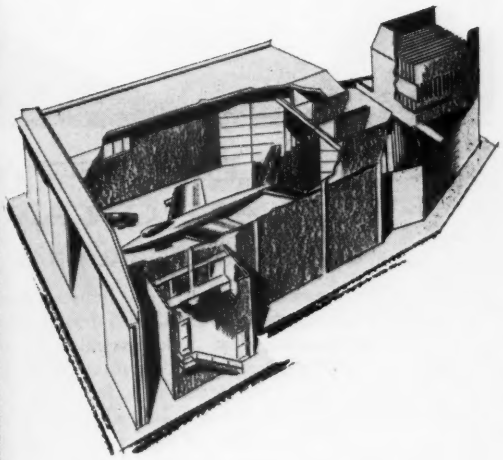

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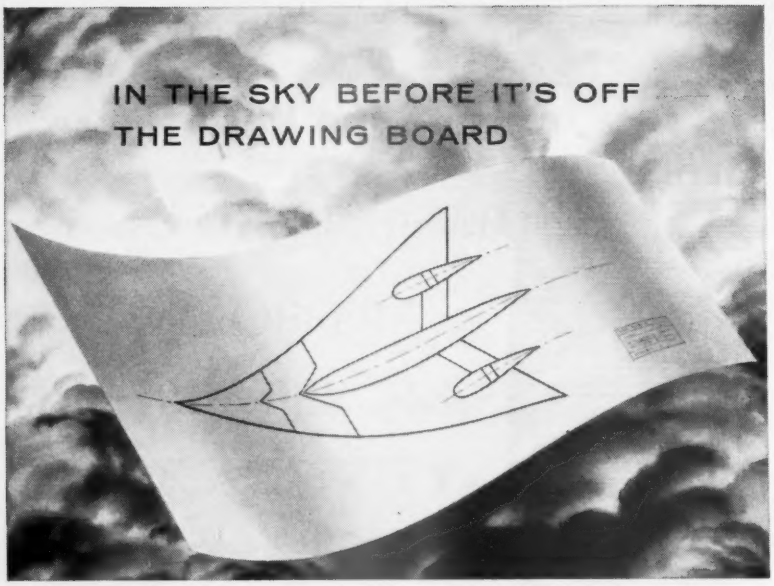

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posium (Co-Sponsored With Convair Division, General Dynamics Corporation). Edited by Morton Alperin, Marvin Stern, and Harold Wooster. (International Series of Monographs on Aeronautical Sciences and Space Flight; Division VII, Astronautics Division, Vol. 1.) New York, Pergamon Press, Symposium Publications Division, 1958. 330 pp., illus., diagrs., tables. $15.

The Astronautics Symposium, convened at San Diego, Calif., February, 1957, had two objectives: to survey the scientific and technological progress of astronautics and to indicate the lines of research needed to be emphasized to facilitate future space exploration. The 42 papers in this volume were presented by participants from industry, the Armed Services, independent research organizations, and leading universities and have not previously appeared in published form.

Contents: Part I. Re-entry: The Re-entry Problem, W. H. Dorrance. Deceleration and Heating of a Body Entering a Planetary Atmosphere from Space, C. Gazely, Jr. Re-entry and Recovery of a High-drag Satellite Initially in Circular Orbit about the Earth, A. J. Eggers, Jr. Planetary Atmospheres, G. Solomon. The Use of Lift for Re-entry from Satellite Trajectories, A. Ferri, L. Feldman, and W. Daskin. Real Gas Effects in the Re-entry Problem, F. R. Riddell. Transition and Turbulent Heating, Including Possible Real Gas Effects, E. R. van Driest.

Part II. Tracking and Communications: Satellite Tracking Techniques, M. Fishman. Tracking and Communication for a Moon Rocket, R. T. Gabler and H. R. O'Mara. Survey of Communications Problems Associated with Space Travel, J. A. Marsh. Microlock: A Minimum Weight Radio Instrumentation System for a Satellite, H. L. Richter, Jr., W. F. Sampson, and R. Stevens.

Part III. Environment and Measurements: The Meteoritic Risk to Space Vehicles, F. L. Whipple. Possibilities for Gas Composition Measurement at Very High Altitudes, N. W. Spencer. Properties of the Atmosphere between 90 and 300 Km, H. K. Kallmann. Effects of Abnormal Solar Activity, W. O. Roberts. Solar X-rays and the Ionosphere, H. Friedman. Interaction of Extreme UV Radiation with Matter, H. E. Hintereggger. The Temperature Equilibrium of a Space Vehicle, J. E. Naugle. Cosmic Rays in Space, H. V. Neher. The Measurement of Cosmic Radiation, Magnetic Field and Ion Density in Interplanetary Space, R. J. Havens. The Concept of an Inhabited High Vacuum Laboratory, R. A. Roche.

Part IV. Propulsion: Summary, W. Bollay. The Optimum Velocity of Propellant Ejection, R. Cornog. The Plasma Jet and its Application, G. M. Giannini. Discussion of Propulsion Systems Present and Future, Y. C. Lee. Remarks at the Propulsion Panel of the Astronautics Symposium, O. E. Rodgers. Propulsion Systems for Space Ships, E. Stuhlinger. A Preliminary Comparison of Potential Propulsion Systems for Space Flight, G. P. Sutton. Rocket Engines for Outer Space, R. A. Truax. Survey of Performance Potentialities on Non-Airbreathing Propulsion Systems, H. von Ohain, B. C. Keith, and R. E. Hunter.

Part V. Orbits: A Precise Attitude Control for Artificial Satellites, H. Oberth. Orbit Studies Using High Speed Digital Computers, W. A. Elfers. Orbit Accuracy and Ranges from Ground-Based Optical Tracking, F. L. Whipple. The Effect of the Earth's Oblateness and Atmosphere on a Satellite Orbit, J. de Nike. Accuracy Requirements for Trajectories in the Earth-Moon System, H. A. Lieske.

Part VI. Human Factors: Introduction, H. Strughold. Human Logistics from the Viewpoint of Space Travel, P. Campbell. The Problems of Maintaining Man at Extreme Altitudes, S. White. Appraisal of Cosmic-Ray Hazards in Extra-Atmospheric Flight, H. J. Schaefer. Areas of Current Space Medical Research, D. G. Simons. Fatigue, Confinement and Proficiency Decrement, G. T. Hauty and R. B. Payne. Current International Situation and the Legal Involvements with Respect to Long Range Missiles and Earth Circling Objects, A. G. Haley. Index.

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Aeronautical Reviews (Continued from page 114)

Fatigue

Further Investigation of Fatigue-Crack Propagation in Aluminum-Alloy Box Beams. H. F. Hardrath and H. A. Leybold. *U.S., NACA TN 4246*, June, 1958. 23 pp. Investigation of fatigue-crack propagation and accompanying stress distribution by subjecting several designs of built-up box beams to fatigue tests at one load level. The rate of crack propagation in specimens made of 7075 material is shown to be more rapid than that in equivalent specimens made of 2024 material.

Plates

O Teorii Izgiba Plastinok Raissnera. A. L. Gol'denveizer. *AN SSSR Otd. Tekh. Nauk Izv.*, Apr., 1958, pp. 102–109. In Russian. Evaluation of the theory on bending of elastic plates.

Sandwich Construction

High Temperature Sandwich Structure. *AIA ATC Rep. ARTC-17*, June 15, 1958. 112 pp. 10 refs.

Testing Methods

Some Developments and Applications of Brittle Lacquers; A Survey of Published Work and Some Original Contributions. III. Appendix I—Specification of Lacquers Incorporating a Ketone Resin. Appendix II—The Influence of Variables on the Behaviour of a Sprayed Brittle Lacquer Coating. J. R. Linge. *Aircraft Eng.*, June, 1958, pp. 173–179.

Thermal Stress

Thermal Stresses in Design. IV—Causes of Fatigue in Ductile Materials. S. S. Manson. *Mach. Des.*, Aug. 21, 1958, pp. 110–113.

On a Complementary Energy Principle in Linear Thermoelasticity. G. Herrmann. *J. Aero/Space Sci.*, Oct., 1958, p. 660. AFOSR-supported establishment of the complementary energy principle associated with Biot's formulation. The equations of linear thermoelasticity are given.

Thermal Displacement in a Non-Homogeneous Elastic Semi-Infinite Space Caused by Sudden Heating of the Boundary. Józef Ignaczak. *Arch. Mech. Stosowanej*, No. 2, 1958, pp. 147–154. Derivation of a nonsteady field of thermal displacement in a nonhomogeneous semispace. This generalization may be used for the description of the phenomenon of wave motion caused by sudden heating of the edge of a multilayer elastic semispace.

A Comparison of Two Methods for Calculating Transient Temperatures of Thick Walls. J. J. Buglia and Helen Brinkworth. *U.S., NACA TN 4343*, Aug., 1958. 19 pp.

Wings

Further Remarks on the Torsional Rigidity of Thermally Stressed Wings. R. L. Bisplinghoff. *J. Aero/Space Sci.*, Oct., 1958, pp. 657, 658. Comparison of theory and experiment for finitely twisted flat plates subjected to a chordwise temperature distribution.

Thermodynamics

O Novoi Edinitse Teplovoi Energii. V. P. Romadin. *Teploenergetika*, June, 1958, pp. 30–33. In Russian. Evaluation of the application of a new thermal unit in thermal engineering.

Nomogrammy dlia Rascheta Temperaturnogo Polia Tverdykh Tel, Okhlazhdaemykh (Nagrevaemykh) v Srede s Postoiannoi Temperaturoi. D. A. Labuntsov. *Teploenergetika*, June, 1958, pp. 87–89. In Russian. Presentation of nomograms for the calculation of temperature fields in solid bodies cooled (or heated) in a medium of constant temperature.

Polynomial Expressions for the Specific Heat and Prandtl Number of Air. D. W. Boekemeier. *J. Aero/Space Sci.*, Oct., 1958, pp. 658, 659.

Opredelenie Elementarnykh Funktsii Uravneniia Sostoianiia Real'nogo Gaza po Opytnym Termicheskim Dannym. Ia. Z. Kazavchinskii. *Teploenergetika*, June, 1958, pp. 44–48. In Russian. Derivation of basic functions for the equation of state of a gas based on thermal data.

Combustion

Studies of OH, CO, CH, and C_2 Radiation from Laminar and Turbulent Propane-Air and Ethylene-Air Flames. T. P. Clark. *U.S., NACA TN 4266*, June, 1958. 23 pp. 14 refs. Isolation of OH, CO, CH, and C_2 radiations from propane-air and ethylene-air flames, and determination of the variation of emitter intensity with equivalence ratio. Radiation ratios in different regions of laminar and turbulent ethylene-air flames are measured.

Excitation of Spectra of OH in Hydrogen Flames and its Relation to Excess Concentrations of Free Atoms. Monique Charton and A. G. Gaydon. *Royal Soc. (London) Proc., Ser. A*, May 6, 1958, pp. 84–92. 11 refs.

Heat Transfer

A Review of Heat Transfer Literature 1957. E. R. G. Eckert, J. P. Hartnett, and T. F. Irvine, Jr. *Mech. Eng.*, June, 1958, pp. 64–75. 267 refs.

A Numerical Method of Solving a Heat Flow Problem with Moving Boundary. L. W. Ehrlich. *Assoc. Comp. Mach. J.*, Apr., 1958, pp. 161–176. 10 refs. Presentation of an analytical expression for the location of the moving boundary in the form of infinite series.

Uravneniia dlia Rascheta Poverkhnostnogo Natiazheniia Zhidkostei. L. D. Voliak. *Teploenergetika*, June, 1958, pp. 33–37. 10 refs. In Russian. Derivation of solutions for the calculation of surface tension of liquids applicable to a wide range of temperatures.

O Edinstvennosti Resheniі Uravneniia Slabo Statsionarnoi Teplovoi Konvektsii. M. M. Farzetdinov. *Prikl. Mat. i Mekh.*, Mar.-Apr., 1958, pp. 286–288. In Russian. Analysis of the singularity of solutions for the equations of weak, stationary heat-transfer problems.

Heat Transmission Through Fins and Finned Cylinders. K. Löhner and G. Choné. (*MTZ*, Stuttgart, Dec., 1957, pp. 373–377.) *Engr. Dig.*, Mar., 1958, pp. 111–114.

VTOL & STOL

Foretaste of the Caravan; HDM.105 Handling and HDM.106 Prospects. *Flight*, June 6, 1958, pp. 776, 777. Discussion of an STOL aircraft which uses a high-aspect ratio wing (20.5:1).

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